PRINCETON APPLIED RESEARCH®

INSTRUCTION MANUAL

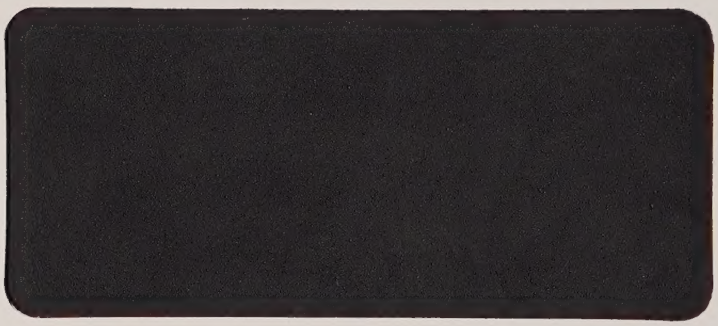
TWO PHASE/VECTOR LOCK-IN AMPLIFIER

Model 129

MP MASTER
MA29048

PRINCETON APPLIED RESEARCH CORPORATION

PRINCETON, NEW JERSEY



INSTRUCTION MANUAL

TWO PHASE/VECTOR LOCK-IN AMPLIFIER

Model 129

THIS MANUAL APPLIES SPECIFICALLY TO MODEL 129 SERIAL NO.

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NOTE: Material relating to changes, if any, will be found in envelope at rear of manual.

M193; 8/72

WHEN YOUR EQUIPMENT REQUIRES SERVICE

A. Contact the factory (609-452-2111) or your local PAR representative (see list at rear of manual) to discuss the problem. In many cases it will be possible to expedite servicing by localizing the problem to a particular plug-in circuit board.

B. If it is necessary to send any equipment back to the factory, we need the following information.

(1) Model # and serial #.

(2) Your name (instrument user).

(3) Your address.

(4) Address to which instrument should be returned.

(5) Your telephone number and extension.

(6) Symptoms (in detail, including control settings).

(7) Your purchase order number for repair charges (does not apply to repairs in warranty).

(8) Shipping instructions (if you wish to authorize shipment by any method other than normal surface transportation).

C. U.S. CUSTOMERS - Ship the equipment being returned to:

Princeton Applied Research Corporation
7 Roszel Road
(Off Alexander Road, East of Route 1)
Princeton, New Jersey

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E. Address correspondence to:

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Princeton, New Jersey 08540

Phone: (609) 452-2111
TELEX: 84-3409

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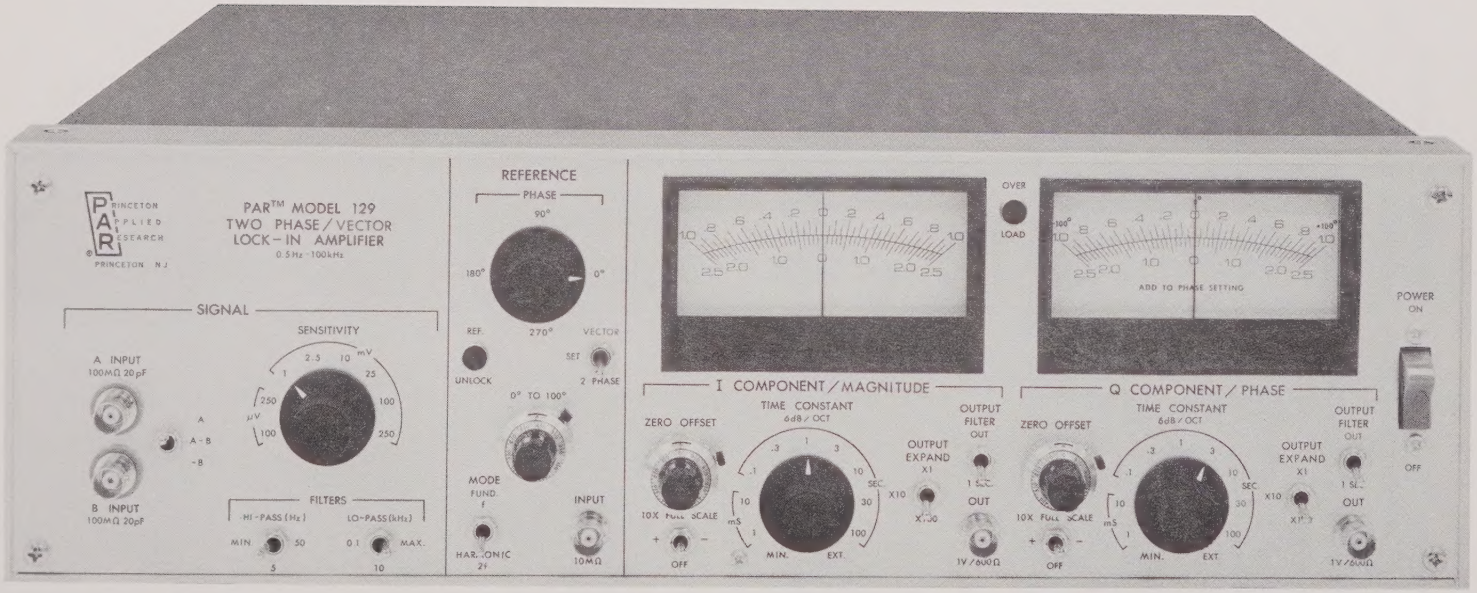
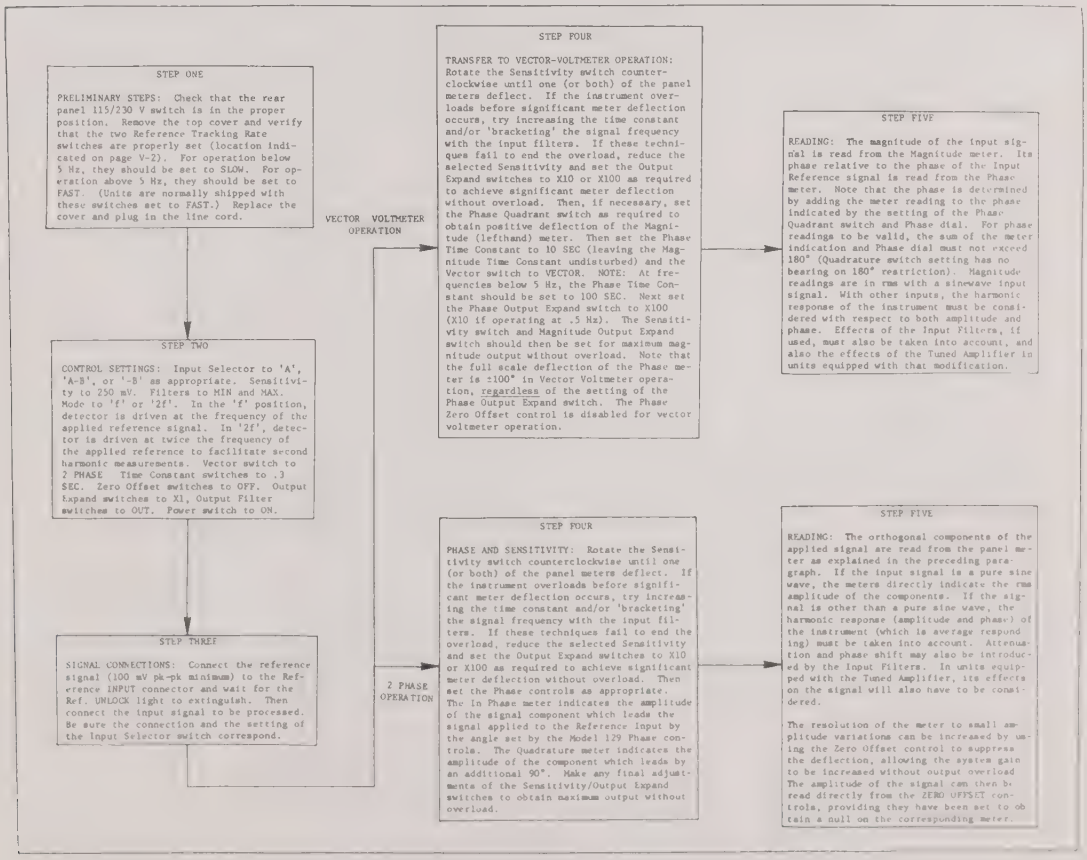

PRINCETON APPLIED RESEARCH
PRINCETON N.J.
PAR™ MODEL 129
TWO PHASE / VECTOR
LOCK-IN AMPLIFIER
0.5Hz - 100kHz
SIGNAL
SENSITIVITY
A INPUT
100MΩ 20pF
B INPUT
100MΩ 20pF
A
A - B
-B
FILTERS
HI-PASS (Hz)
LO-PASS (kHz)
MIN
MAX.
REFERENCE
PHASE
90°
180°
0°
270°
REF.
UNLOCK
VECTOR
SET
2 PHASE
0° TO 100°
MODE
FUND.
HARMONIC
2f
INPUT
10MΩ
OVER
LOAD
I COMPONENT / MAGNITUDE
ZERO OFFSET
10X FULL SCALE
OFF
TIME CONSTANT
6dB / OCT.
MIN.
EXT.
OUTPUT EXPAND
X1
X10
X100
OUTPUT FILTER
OUT
1 SEC
1V / 600Ω
Q COMPONENT / PHASE
ADD TO PHASE SETTING
POWER
ON
OFF

SECTION I
CONDENSED OPERATING INSTRUCTIONS

The following condensed operating instructions are provided as an assistance in placing the Model 129 Two Phase/Vector Lock-In Amplifier into operation as quickly as possible. Generally speaking, these condensed instructions will allow good results to be obtained in most instances. However, because of the brevity of these instructions, many considerations having importance in particular applications have been foregone. For this reason, it is advisable to read Section IV, the complete Operating Instructions, to be assured of achieving optimum performance. NOTE: As written, these condensed instructions do not apply to units having either the Internal Oscillator or Tuned Amplifier modifications. If the unit in question has either or both of these modifications, the operator is referred to Subsections 4.7 and 4.8.


STEP ONE
PRELIMINARY STEPS: Check that the rear panel 115/230 V switch is in the proper position. Remove the top cover and verify that the two Reference Tracking Rate switches are properly set (location indicated on page V-2). For operation below 5 Hz, they should be set to SLOW. For operation above 5 Hz, they should be set to FAST. (Units are normally shipped with these switches set to FAST.) Replace the cover and plug in the line cord.
STEP TWO
CONTROL SETTINGS: Input Selector to 'A', 'A-B', or '-B' as appropriate. Sensitivity to 250 mV. Filters to MIN and MAX. Mode to 'f' or '2f'. In the 'f' position, detector is driven at the frequency of the applied reference signal. In '2f', detector is driven at twice the frequency of the applied reference to facilitate second harmonic measurements. Vector switch to 2 PHASE. Time Constant switches to .3 SEC. Zero Offset switches to OFF. Output Expand switches to X1, Output Filter switches to OUT. Power switch to ON.
STEP THREE
SIGNAL CONNECTIONS: Connect the reference signal (100 mV pk-pk minimum) to the Reference INPUT connector and wait for the Ref. UNLOCK light to extinguish. Then connect the input signal to be processed. Be sure the connection and the setting of the Input Selector switch correspond.
VECTOR VOLTMETER OPERATION
2 PHASE OPERATION
STEP FOUR
TRANSFER TO VECTOR-VOLTMETER OPERATION: Rotate the Sensitivity switch counterclockwise until one (or both) of the panel meters deflect. If the instrument overloads before significant meter deflection occurs, try increasing the time constant and/or 'bracketing' the signal frequency with the input filters. If these techniques fail to end the overload, reduce the selected Sensitivity and set the Output Expand switches to X10 or X100 as required to achieve significant meter deflection without overload. Then, if necessary, set the Phase Quadrant switch as required to obtain positive deflection of the Magnitude (lefthand) meter. Then set the Phase Time Constant to 10 SEC (leaving the Magnitude Time Constant undisturbed) and the Vector switch to VECTOR. NOTE: At frequencies below 5 Hz, the Phase Time Constant should be set to 100 SEC. Next set the Phase Output Expand switch to X100 (X10 if operating at .5 Hz). The Sensitivity switch and Magnitude Output Expand switch should then be set for maximum magnitude output without overload. Note that the full scale deflection of the Phase meter is ±100° in Vector Voltmeter operation, regardless of the setting of the Phase Output Expand switch. The Phase Zero Offset control is disabled for vector voltmeter operation.
STEP FIVE
READING: The magnitude of the input signal is read from the Magnitude meter. Its phase relative to the phase of the Input Reference signal is read from the Phase meter. Note that the phase is determined by adding the meter reading to the phase indicated by the setting of the Phase Quadrant switch and Phase dial. For phase readings to be valid, the sum of the meter indication and Phase dial must not exceed 180° (Quadrature switch setting has no bearing on 180° restriction). Magnitude readings are in rms with a sinewave input signal. With other inputs, the harmonic response of the instrument must be considered with respect to both amplitude and phase. Effects of the Input Filters, if used, must also be taken into account, and also the effects of the Tuned Amplifier in units equipped with that modification.
STEP FOUR
PHASE AND SENSITIVITY: Rotate the Sensitivity switch counterclockwise until one (or both) of the panel meters deflect. If the instrument overloads before significant meter deflection occurs, try increasing the time constant and/or 'bracketing' the signal frequency with the input filters. If these techniques fail to end the overload, reduce the selected Sensitivity and set the Output Expand switches to X10 or X100 as required to achieve significant meter deflection without overload. Then set the Phase controls as appropriate. The In Phase meter indicates the amplitude of the signal component which leads the signal applied to the Reference Input by the angle set by the Model 129 Phase controls. The Quadrature meter indicates the amplitude of the component which leads by an additional 90°. Make any final adjustments of the Sensitivity/Output Expand switches to obtain maximum output without overload.
STEP FIVE
READING: The orthogonal components of the applied signal are read from the panel meter as explained in the preceding paragraph. If the input signal is a pure sine wave, the meters directly indicate the rms amplitude of the components. If the signal is other than a pure sine wave, the harmonic response (amplitude and phase) of the instrument (which is average responding) must be taken into account. Attenuation and phase shift may also be introduced by the Input Filters. In units equipped with the Tuned Amplifier, its effects on the signal will also have to be considered.
The resolution of the meter to small amplitude variations can be increased by using the Zero Offset control to suppress the deflection, allowing the system gain to be increased without output overload. The amplitude of the signal can then be read directly from the ZERO OFFSET controls, providing they have been set to obtain a null on the corresponding meter.

SECTION II
CHARACTERISTICS

2.1 INTRODUCTION

The Model 129 Two Phase/Vector Lock-In Amplifier allows one to simultaneously measure either the in-phase and quadrature components of a signal or the amplitude and phase angle of the equivalent vector. These measurements can be made over a frequency range of 0.5 Hz to 100 kHz. Moreover, these measurements can be made even if the signal of interest is slowly drifting in frequency and is obscured by high level background noise.

When operated as a two-phase lock-in amplifier, internal circuitry automatically maintains a 90° relationship between the two channels to within 0.2° across the entire operating frequency range. Both the in-phase and quadrature channels are provided with independent output expand switches that permit the sensitivity to be expanded by a factor of X10 or X100. Each channel is also provided with independent output filtering that offers a switch-selectable choice of nine calibrated time constants ranging from 1 ms to 100 s. Low internal noise combined with exceptional orthogonality, high sensitivity, low drift, and independent output expansion and filtering make the Model 129 the ideal choice for use in all applications requiring two-phase detection of low level signals.

When operated as a vector voltmeter, the Model 129 simultaneously measures both the signal's amplitude and phase angle with respect to the reference signal. When the Vector switch is set to VECTOR, internal circuitry automatically locks onto the vector signal and provides the appropriate outputs to the two panel meters, providing a direct readout of both values.

The versatility of the Model 129 can be extended significantly by inclusion of an optional internal oscillator that provides a reference signal of up to 3.5 V rms for use in experiments where no external reference signal can be supplied. A tuned amplifier having a Q-of-5 is also available optionally. The selectivity provided by the tuned amplifier can significantly improve the overload tolerance of the instrument in many applications.

The Model 129 can also function as a standard lock-in amplifier as well, suitable for high sensitivity measurements of low-level signals in many scientific applications. Typical uses include ac photometry, ac bridge balancing, Hall effect studies, nuclear magnetic resonance, and many others in the fields of chemistry, physics, bio-sciences, and engineering.

2.2 SPECIFICATIONS

2.2A SIGNAL CHANNEL

(1) INPUT TYPE: Single-ended or differential as selected by front-panel switch.

(2) INPUT IMPEDANCE: 100 MΩ shunted by no more than 20 pF.

(3) SENSITIVITY

(a) AS A TWO-PHASE LOCK-IN AMPLIFIER: Eight full-scale ranges in 1-2.5-10 sequence from 100 μV to 250 mV set the sensitivity for both channels simultaneously. Each channel additionally has an independent three-position Output Expand switch which can be set to X1, X10, or X100, allowing the sensitivity of the two channels to be independently set. By using these switches, the maximum sensitivity is increased from 100 μV full scale to 1 μV full scale. (See Demodulator Specifications, 2.2C, for additional information concerning the Output Expand switches.)

(b) AS A VECTOR VOLTMETER: Magnitude sensitivity as stated above for two-phase lock-in amplifier operation. Phase angle measurement sensitive to changes smaller than 0.01°. Phase meter sensitivity is ±100° full scale.

(4) FREQUENCY RANGE: 0.5 Hz to 100 kHz.

(5) COMMON MODE REJECTION: Better than 100 dB at 1 kHz.

(6) MAXIMUM COMMON-MODE VOLTAGE: 1 V pk-pk.

(7) DETECTOR BIAS: Adjustable from 0 to ±15 V through nearly any desired resistance by inserting appropriate resistors on internal preamplifier board (see page VIII-2). Facilitates operation with external signal sources which require biasing, such as diode-type photodetectors.

(8) NOISE: Less than 10 $nV/\sqrt{Hz}$ at 1 kHz.

(9) SYSTEM GAIN STABILITY: Better than 0.1%/°C.

(10) GAIN LINEARITY: 0.05%.

(11) OVERALL ACCURACY: ±2%.

(12) HIGH-PASS FILTER: Switch selectable 6 dB/octave high-pass filter which can be set to 3 dB down frequencies of 50 kHz, 5 kHz, or MIN (below 0.5 Hz).

(13) LOW-PASS FILTER: Switch selectable 6 dB/octave low-pass filter which can be set to 3 dB down frequencies of 100 Hz, 10 kHz, or MAX (greater than 100 kHz).

2.2B REFERENCE CHANNEL

The Model 129 reference channel automatically locks onto and tracks an applied reference signal over the entire operating frequency range of the instrument. As a result of this automatic tracking, changes in the reference frequency will cause no measurement error if the input signal undergoes the same frequency shifts.

(1) FREQUENCY RANGE

Position of Tracking Rate Switches (Internal)	Range
FAST	5 Hz to 100 kHz
SLOW	0.5 Hz to 100 kHz

Faster lock-on time and slewing rate obtained with switches set to FAST make this range preferable except when operating below 5 Hz.

(2) OPERATING MODES

(a) 'f' MODE (fundamental): Instrument locks onto any external reference signal meeting the minimum reference signal requirements. Reference input to demodulator driven at the frequency of the applied reference.

(b) '2f' MODE (harmonic): As above except that the demodulator is driven at twice the frequency of the applied reference signal to facilitate second harmonic measurements. Input frequency is limited to 50 kHz (demodulator driven at 100 kHz).

(3) INPUT IMPEDANCE: 10 MΩ shunted by no more than 20 pF.

(4) MINIMUM REFERENCE SIGNAL REQUIREMENTS: The reference channel will lock in both frequency and phase to virtually any external voltage waveform having amplitude excursions of at least 50 mV on each side of the mean and crossing the mean only twice each cycle. Waveform must remain on each side for at least 100 ns. Maximum allowable input voltage is ±200 V dc.

(5) TYPICAL ACQUISITION TIME: Either 2N seconds (Rate switches to FAST) or 10N seconds (Rate switches to SLOW), where N is the number of octaves separating the initial and final frequencies. When reference signal is first applied, initial frequency is at some very low undefined value.

(6) PHASE: A calibrated ten-turn potentiometer provides 0-100° phase shift accurate to within 0.2°. Resolution is 0.1°. A four-position Quadrant switch provides 90° Phase shift increments accurate to 0.2°.

(7) DETECTOR BIAS: Internal network allows dc bias current of either polarity (0 to ±15 V) to be provided at the Reference Input connector to facilitate operation in situations where the reference signal is

derived from a diode or other device requiring biasing (see page VIII-4).

2.2C DEMODULATOR AND FINAL AMPLIFIER

(1) MODES

(a) TWO PHASE LOCK-IN AMPLIFIER (Vector switch set to 2 PHASE): Provides simultaneous measurement of both the in-phase and quadrature components of signal being measured. Internal circuitry automatically maintains a 90° relationship between the in-phase and quadrature channels to within 0.2° across the entire operating frequency range.

(b) VECTOR VOLTMETER (Vector switch to VECTOR): Provides simultaneous measurement of the signal's amplitude and phase angle relative to the reference signal. Phase angle meter calibrated to ±100°. Meter readout must be added to Phase Quadrant and Phase dial setting indications. Phase analog output accuracy is better than 0.2°. Phase shifts introduced by the signal channel at extreme frequencies can be measured easily and thus taken into account.

(2) OVERLOAD CAPABILITY: Up to 200 times full-scale up to maximum at the input of 400 mV rms. Overload capability is defined as the ratio, at the input of the Model 129, of the maximum pk-pk non-coherent signal which can be applied without overloading the Model 129 to the pk-pk coherent signal required to yield full-scale Model 129 output. Note that, expressed as the ratio of the pk-pk non-coherent signal to the rms value of the coherent signal required for full-scale output, this number can be as great as 700. Maximum acceptable signal is a 400 mV rms sinewave.

(3) DYNAMIC RANGE, DC OUTPUT STABILITY, AND OUTPUT EXPANSION: The Output Expand switches permit the tradeoff of stability for increased overload capability to match the instrument's characteristics to the signal being measured. The following table lists both the stability and Overload capability at each switch setting.

OUTPUT EXPAND SETTING	OUTPUT STABILITY (ppm/°C)	OVERLOAD CAPABILITY*
X1	200	2 X full scale
X10	300	20 X full scale
X100	1000	200 X full scale

*See preceding specification for definition of Overload Capability.

(4) NON-COHERENT REJECTION: 50 ppm maximum. Non-coherent rejection is defined as that offset which results from applying a non-coherent signal having a pk-pk amplitude 200 times the pk-pk amplitude of the coherent signal required to obtain full-scale output.

Example: With a non-coherent signal applied having a pk-pk amplitude

200 times the pk-pk coherent signal required to obtain full-scale output (Output Expand at X100), there will occur an offset at the output caused by the noncoherent input signal. The amplitude of this offset will be no greater than 50 x 10^{-6} x 200 of f.s. output = 10 mV (f.s. = 1 V).

(5) TIME CONSTANT

(a) TWO-PHASE MODE: Each channel is provided with an independent output filter offering a switch selectable choice of nine time constants ranging from 1 ms to 100 s plus MIN (less than 1 ms) and EXT. The External position allows the time constant to be determined by capacitors connected to a rear-panel connector (one capacitor required for each channel).

A Post filter is also provided for each channel which allows an additional 6 dB/octave single-section filter having a time constant of one second to be inserted.

(b) VECTOR VOLTMETER MODE: The Magnitude Time Constant switch functions as described in 'a'. The Phase Angle Time Constant switch stabilizes the loop and provides smoothing useful for measuring noisy signals. For loop stability, Time Constant switch should be set to 10 s or higher. Setting Output Expand to X100 (recommended) gives much more rapid response than one would expect from relatively long required 'time constant'.

(6) ZERO SUPPRESS: Calibrated ten-turn potentiometer is provided for each channel permitting up to ±1000% of full scale to be suppressed when the Output Expand switch is set to X10 or X100, and up to 200% of full scale when the switch is set to X1.

2.2D OUTPUTS

(1) OUTPUT VOLTAGE: ±1 V corresponds to full-scale meter deflection.

(2) PANEL METERS: Two 1½% tracking accuracy zero-center meters provide simultaneous readout of the in-phase and quadrature amplitudes or of the magnitude and phase of the equivalent vector. Where linearity is critical requirement, measurement of analog output is recommended.

(3) RECORDER: ±1 V full scale is available at both a front-panel BNC connector and at a rear panel double banana jack for each channel. Output impedance is 600 ohms.

2.2E GENERAL SPECIFICATIONS

(1) AMBIENT TEMPERATURE OPERATING RANGE: 15°C to 45°C.

(2) AUXILIARY POWER OUTPUT: ±15 V regulated dc at 20 mA available at rear-panel connector.

(3) OVERLOAD INDICATION: Front-panel light indicates overload at all

critical points in the instrument.

(4) POWER REQUIREMENTS: 100-130 or 200-260 V ac, 50-60 Hz, 14 watts. Unit can also be powered from batteries by supplying ±20 to ±30 V to rear-panel connector. Batteries must be able to supply at least 300 mA.

(5) SIZE: 17-3/4" W x 5-1/4" H x 14" D (45 cm W x 13.3 cm H x 36 cm D).

(6) ACCESSORIES: An accessory kit is available which provides special side brackets for mounting the Model 129 in a standard 19 inch rack. Also included are replacement fuses and lamps.

(7) WEIGHT: 14 lb.

2.2F MODIFICATIONS

(1) MONITOR MODIFICATION (Model 129/97): Three rear-panel BNC connectors are installed which permit monitoring of: (1) Output of Signal Channel before demodulation (please note that the Signal Channel monitor is provided as part of the Tuned Amplifier modification as well), (2) Square wave output of Reference Channel, and (3) Full-wave demodulated Mixer output ahead of the Time Constant filter.

(2) TUNED AMPLIFIER MODIFICATION (Model 129/98): Internal plug-in board is available which provides a tuned bandpass or notch characteristic at a Q-of-5. The frequency can be adjusted over a 3:1 range by means of a rear-panel adjustment, and can be set to any frequency from 1 Hz to 100 kHz by changing capacitors mounted on securing clips located on the plug-on circuit board. This option, operated in the Notch mode to remove the fundamental, is particularly useful for harmonic detection.

(3) INTERNAL OSCILLATOR MODIFICATION (Model 129/99): An internal low distortion oscillator is available which provides a sinewave output adjustable from 0-to-10 V pk-pk at 600 ohms. The frequency is adjustable over about a 3:1 range by means of a rear-panel adjustment, with the actual frequency range spanned by the adjustment being determined by a pair of internal capacitors mounted on the oscillator circuit board. Operation from about 1 Hz to 100 kHz is possible.

SECTION III
INITIAL CHECKS

3.1 INTRODUCTION

The following procedure is provided to facilitate initial performance checking of the Model 129. In general, this procedure should be performed after inspecting the instrument for shipping damage (any noted to be reported to the carrier and to Princeton Applied Research Corporation), but before using the instrument for experimental measurements. Should any difficulty be encountered in carrying out these checks, contact the factory or one of its representatives, a list of whom appears at the end of the manual. It might be noted that it is not the purpose of these checks to demonstrate that the instrument meets all specifications, but rather simply to show that it is functioning normally. If normal indications are obtained for the functions checked, one may reasonably assume that those functions which are not checked are working properly as well.

3.2 EQUIPMENT NEEDED

(1) Sinewave Oscillator to provide a 100 mV rms sinewave at 1 kHz. NOTE: If the instrument to be checked is equipped with the Tuned Amplifier modification, then the oscillator will have to provide a 100 mV rms sinewave at the tuned frequency, which will probably be other than 1 kHz. If the instrument in question is equipped with the Internal Oscillator modification, no external oscillator will be required. This applies whether or not the unit is equipped with the Tuned Amplifier modification.

(2) General purpose oscilloscope. This item is required only in the case of units having the Tuned Amplifier modification.

(3) Suitable cables for interconnecting the above instruments.

3.3 PROCEDURE

(1) Check the position of the rear-panel 115/230 switch. Be sure the number showing in the window corresponds to the line voltage to be used.

(2) With the Power switch set to OFF, plug in the line cord.

(3) Set the Model 129 controls as follows.

Input Selector ---------- A
Sensitivity ---------- 100 mV
Filters
    HI-PASS ---------- MIN.
    LO-PASS ---------- MAX.
Phase
    Quadrant switch ---------- 270°
    Phase dial ---------- 90°

Mode	f
Vector switch	2 PHASE
Zero Offset dials	1.00 (one turn from fully counterclockwise position)
Zero Offset switches	OFF
Output Expand switches	X1
Time Constant switches	.3 SEC.
Output Filter switches	OUT
Reference Tracking Rate switches (see page V-2 for location)	FAST (unless unit is shipped with Tuned Amplifier or Internal Oscillator set for frequency below 5 Hz, in which case switches should be set to SLOW). NOTE: Instruments are normally shipped with these switches set to FAST. Be sure cover is back in position before proceeding.
Power	ON

(4) Applies only to units NOT equipped with the Internal Oscillator modification. If the Model 129 has this modification, go to step 5.

Connect the output of the external oscillator (set for 250 mV rms sinewave output at 1 kHz) to both the 'A' and Reference Inputs. If the unit in question has the Tuned Amplifier modification, set the oscillator to the tuned frequency.

(5) Applies only to units having the Internal Oscillator modification.

Connect a cable from the rear-panel REF. OSC. OUT connector to the front-panel 'A' Input. There is no need to connect this signal to the Reference Input connector (labeled MONITOR in units equipped with the Oscillator modification). The connection to the Reference Channel is made internally at the factory. The rear-panel REF. AMPLITUDE adjustment should be set so that the amplitude of the signal at the REF. OSC. OUT connector is nominally 100 mV rms (280 mV pk-pk).

(6) Applies only to units having the Tuned Amplifier modification. In the case of units not having the modification, go directly to step 7.

(a) Connect the oscilloscope to the rear-panel SIG. MON. connector.

(b) Vary the frequency of the signal applied to the 'A' Input (use the rear-panel REF. OSC. FREQ. ADJ. control in units equipped with an Internal Oscillator) for peak signal amplitude as observed with the oscilloscope.

(7) After allowing a few minutes for the REF. UNLOCK light to extinguish and for internal phase circuits to stabilize, carefully adjust the Phase dial for '0' indication on the Quadrature meter. Then adjust the level of the signal applied to the 'A' Input for exactly full

scale indication on the In Phase meter. Touch up the Phase dial setting for '0' on the Quadrature meter if necessary.

(8) Set the Quadrant switch to 180°. The relative meter indications should reverse, that is, the In Phase meter should indicate '0' ±2% of full scale and the Quadrature meter should indicate full scale ±2%.

(9) Set the Quadrature Zero Offset switch to '+'. The Quadrature meter should now indicate '0' ±3% of full scale. Gradually rotate the Quadrature Zero Offset dial counterclockwise. The Quadrature meter reading will increase as the dial setting decreases, and will reach full scale ±5% of full scale when the dial is fully counterclockwise. Reset the Quadrature Offset switch to OFF.

(10) Set the In Phase Zero Offset switch to '-'. The In Phase panel meter should indicate full scale to the right, plus or minus three percent. Gradually rotate the In Phase Zero Offset dial counterclockwise. The In Phase panel meter indication will decrease as the dial setting decreases. When the dial is fully counterclockwise, the meter will indicate '0' ±5% of full scale. Set the In Phase Zero Offset toggle switch to OFF.

(11) Reset the Phase Quadrant switch to 270°. The In Phase meter will indicate full scale and the Quadrature meter zero.

(12) Set the Quadrature/Phase Time Constant switch to 10 SEC (100 SEC if frequency is below 5 Hz). Then set the Vector switch to VECTOR and the Phase Output Expand switch to X100 (X10 if frequency is 0.5 Hz). If the operating frequency is 1 kHz and the unit is operating without a tuned amplifier, the Phase meter should indicate 0° ±2°. If the tuned amplifier is in use, then any slight error in setting the tuned frequency could introduce a phase shift of several degrees. Also, if operating near the frequency extremes of the instrument, a large phase offset could be observed.

(13) Note and record the setting of the Phase dial. Then begin rotating the Phase dial counterclockwise. The Quadrature/Phase panel meter indication will linearly increase. When the dial is fully counterclockwise, the meter phase indication will be within 5° of the dial setting recorded at the beginning of this step.

(14) Reset the Vector switch to 2 PHASE. The Overload light should now be on. Then reset the Phase Output Expand switch to X1 and the associated Time Constant switch back to 0.3 SEC. The Overload lamp should extinguish.

This completes the initial checks. If the indicated results were obtained, one can be reasonably sure that the Model 129 is functioning normally.

SECTION IV
OPERATING INSTRUCTIONS

4.1 INTRODUCTION

Although operation of the Model 129 is straightforward, there are a number of factors to consider to achieve optimum performance in all situations. This section of the manual treats these considerations in some detail. Topics covered include grounding, noise performance, harmonic sensitivity, operation in conjunction with the plug-in accessories, and others. For an overall 'quick look' at how the instrument is operated, the operator is referred to Section I, the condensed operating instructions.

4.2 PRELIMINARY CONSIDERATIONS

4.2A POWER REQUIREMENTS

The Model 128 requires 100-130 V ac or 200-260 V ac, 50-60 Hz. The power consumption is 15 watts. The unit may also be powered by batteries by applying dc power to the appropriate pins of the rear-panel octal connector (see BATTERY OPERATION, page IV-25). A rear-panel slide switch determines whether the ac power circuits are connected for operation from 100-130 V or from 200-260 V. For operation from 100-130 V, '115' should show in the window. For operation from 200-260 V, '230' should show.

4.2B FUSING

The Model 129 is protected by a single fuse mounted on its rear panel. A slow-blow 1/4 A fuse is used for operation from 115 V. A slow-blow 1/10 A fuse is used for operation from 230 V. It occasionally happens that a slow-blow fuse fails in shipment as a result of shock and vibration. Hence, if the fuse is found to be bad when the instrument is operated for the first time, it is advisable to try and change the fuse. If-normal operation follows, chances are there are no other problems. However, if the replacement fuse fails, there is something wrong which will have to be corrected before proceeding.

4.2C WARM-UP PERIOD

For most applications, five minutes. Where it is desired to achieve the best possible gain and output stability, allow half an hour.

4.2D OPERATING FREQUENCY

Although one can, in principle, make equally accurate measurements at any frequency within the operating range of the instrument, operation is simplest and least subject to error over a range having as its lower limit, perhaps a few hundred Hz, and as its upper, perhaps 10 kHz. At low frequencies, 1/f noise, including both that which develops in the Model 129 and that which originates in the experiment itself, degrades the signal-to-noise ratio. Increased response and settling time could be a significant problem if one were operating in conjunction with the optional plug-in tuned amplifier at a low

frequency. At high frequencies, radiation and associated pick-up tend to be bothersome. Another high frequency problem is that of signal attenuation as a result of the input cable capacitance. This is especially a problem when working from a high source resistance. Other frequencies to avoid are 60 Hz and its lower order harmonics. By avoiding these frequencies, the operator assures that he will be measuring the signal of interest only, uninfluenced by power frequency pickup, either internal or external.

4.2E GROUNDING

In any system processing low-level signals, proper grounding to minimize the effects of ground loop currents, usually at the power frequency, is an important consideration. In the case of the Model 129, special design techniques have been employed to give a high degree of ground-loop signal rejection in single-ended applications. Even so, it will often prove advisable to operate differentially, even when examining a single-ended signal source, to achieve the greatest possible rejection. Figures IV-1 and IV-2 illustrate this point. Note from Figure IV-1 that the signal source is located inside a grounded enclosure (shield), to which signal source common is attached at one point. The braid of the signal cable is grounded directly to signal source common as well, thereby assuring that no signal currents or ground-loop currents will flow through the shield, a desirable condition for the best possible shielding. The Model 129 is operated single-ended, using the 'A' input. Note that the 'low' side of the amplifier input is not grounded to the chassis directly but by way of a ten ohm resistor. Further note that the braid of the signal cable is returned to this resistor, and not to the chassis. A ground loop generator is indicated as being connected between the chassis of the Model 129 and signal source common. This path would ordinarily consist of the ac ground 'third wire', paralleled by the braids of other cables connecting the system components. The ground loop generator will cause currents at the power frequency to flow through the braid of the signal cable, through the ten ohm resistor, and back through the ac ground path to complete the loop. Because of the ten ohm ground employed in the Model 129, these currents are attenuated over what they would be if the Model 129 input were returned directly to the chassis. More importantly, most of the ground loop signal is dropped across the ten ohm resistor and little across the braid of the signal cable, the ratio being the ten ohms of the resistor to the 10 to 20 milliohms (typical) of the braid resistance. As far as the input of the Model 129 is concerned, the ground loop signal is reduced by this ratio, and the ground loop interference is thus perhaps a factor of five hundred or one thousand less than would be the case without the ten ohm ground.

However, in some applications, this would not be enough. Figure IV-2 shows how this same signal could be measured operating the Model 129 differentially. In this instance, the Model 129 Input Selector is set to 'A-B' and two input cables are used, one connected to the signal source and the other to signal source common. At the source end, the braid of both cables is returned to signal source common. At the lock-in amplifier end, the ten ohm ground serves to attenuate the ground loop currents and maintain a small ground loop signal drop across the braids the same as in Figure IV-1. However, in the first instance, the amplifier 'looked' at the potential difference between the center conductor of the cable and the braid. In the second, it sees the potential difference between the 'A' Input and 'B' Input. The ground loop

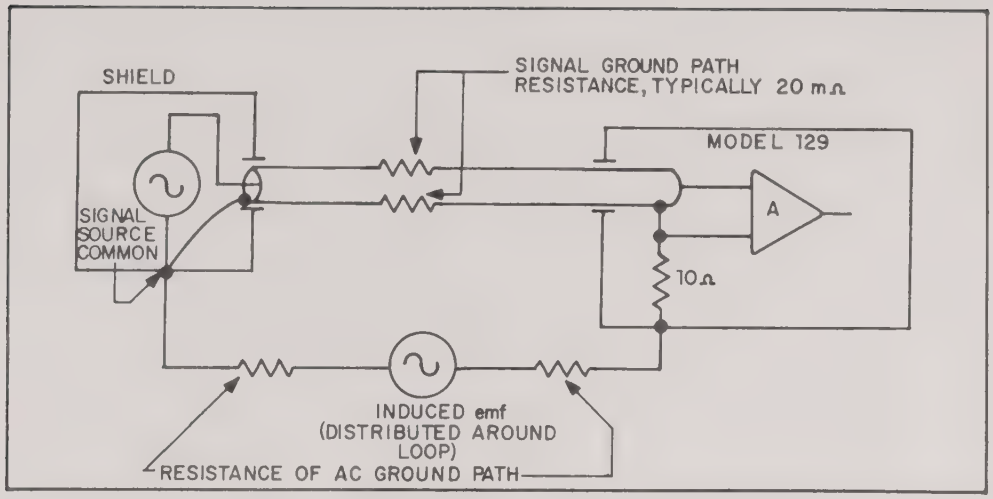


Figure IV-1. GROUND-LOOP SUPPRESSION BY TEN-OHM INPUT GROUND

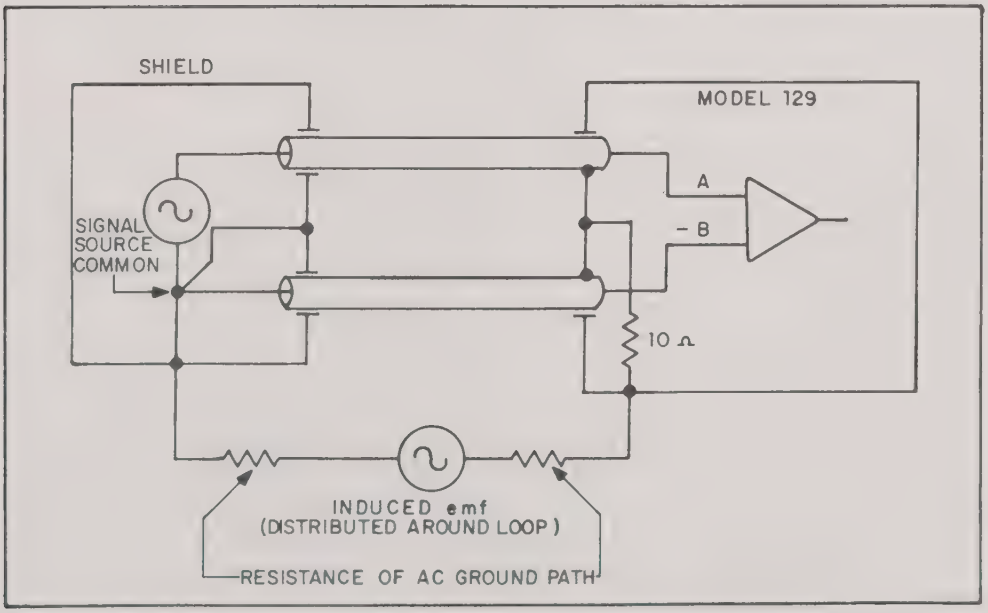


Figure IV-2. DIFFERENTIAL MEASUREMENT OF 'SINGLE-ENDED' SIGNAL

signal current flowing in the signal cable braid is of no consequence. The very high common mode rejection of the amplifier assures that common mode power frequency pickup will not be a problem either.

However, when operating differentially, it is important to take a little trouble to assure that common mode interference arising in ground loops is just that, that is, without a significant differential component. This should not prove a problem as long as both signal cables follow the same path.

Figure IV-3 shows the Model 129 operated differentially to measure an 'off ground' signal. The most important consideration in an application of this type is to be sure that the common mode signal component is not so large as to exceed the common mode input limit of the Model 129, 1 V pk-pk.

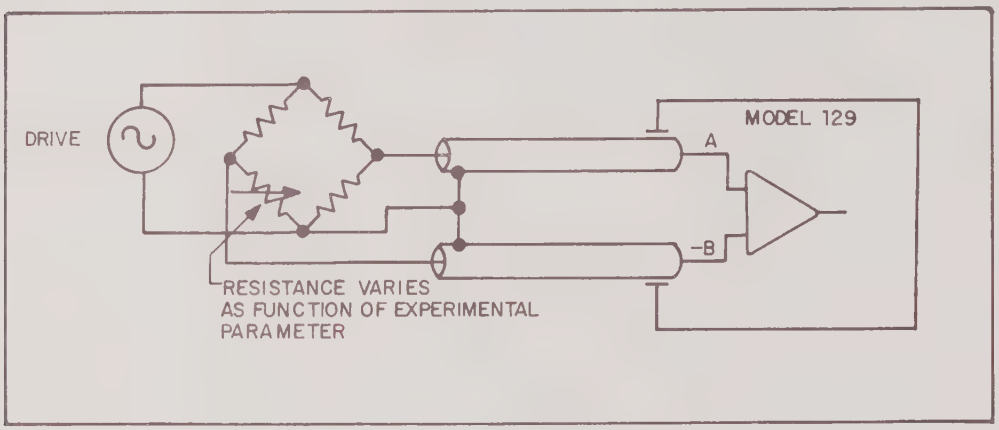


Figure IV-3. DIFFERENTIAL MEASUREMENT OF 'OFF-GROUND' SIGNAL

The reduction of power frequency interference is not the only benefit to be derived from proper grounding and differential operation. A much more serious source of interference is coherent interference at the signal frequency which results when drive signal current is allowed to flow through the braid of the signal cable. Figures IV-4 and IV-5 are provided to illustrate this problem and the steps which can be taken to prevent it. To begin with, Figure IV-4 shows the experiment with just about everything possible 'done wrong'. The lock-in amplifier is operated single ended. The ground connections at the experiment are made to the enclosure, allowing currents to flow through it, and, in particular, the drive signal currents have the opportunity to flow through the braid of the signal cable. The drive signal, in addition to providing the reference input signal to the Model 129, can be presumed to be driving other components of the system as well. Depending on the nature of the experiment, these currents could range from very small to quite large, perhaps even amperes if the experiment involves driving a low impedance coil. Note that the various loads for the drive are represented by a single resistor returned to ground somewhere on the enclosure. Most of this drive signal current can be presumed to flow through the shield back to the

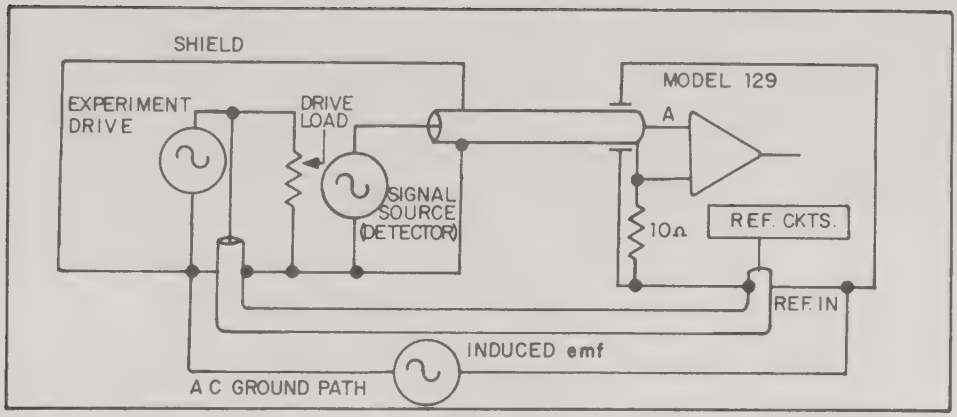


Figure IV-4. EXAMPLE OF EVERYTHING 'DONE WRONG'

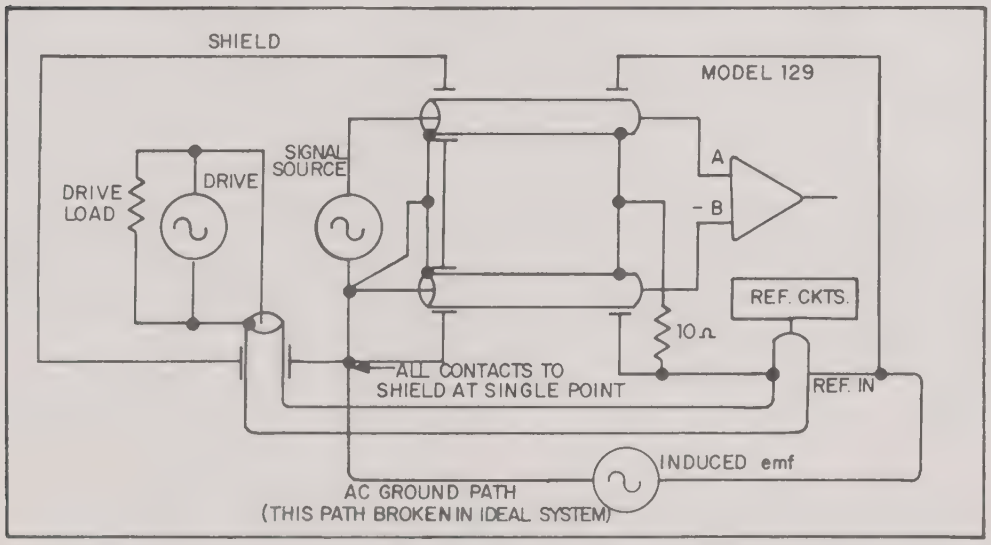


Figure IV-5. ERRORS DEPICTED IN FIGURE IV-4 CORRECTED

drive signal source. However, a small but significant part of it will flow through the parallel path consisting of the braid of the signal cable, the ten ohm resistor, and the braid of the reference signal cable. The voltage drop of this current across the resistance of the signal cable braid, even though attenuated by the ratio of the ten ohm resistor to the braid resistance, can constitute a serious source of interference at low signal levels, particularly in that this interference is coherent, in phase, and directly adds to the signal of interest. It is not hard to envision situations where this interference signal could well be larger at the input of the lock-in amplifier than the signal of interest itself.

Figure IV-5 shows the steps which can be taken to circumvent this problem. All of the drive signal current is returned directly to the drive signal source except for the very small component (reference input resistance of Model 129 is 10 MΩ) which is applied to the Model 129 by way of the Reference Input. Second, no current, whether drive current, reference current, or signal current, is allowed to flow through the experiment shield; the shield contacts ground at one point only. The only coherent signal which can flow through the parallel path of the signal cable braid is a small portion of that allowed by the ten megohm Reference Input resistance. Furthermore, the use of differential operation assures that even this small amount can have no effect. By using the arrangements indicated, one could operate with very large drive currents without concern that they might contaminate the signal of interest. If electrostatic coupling of the drive signal to the detector is a problem, mounting a conducting material around the signal source detector should prove helpful. The electrostatic shield should be connected to the system at but one point, signal source common.

4.2F NOISE

Any electronic signal processing system adds noise to that already accompanying the signal to be measured, and the Model 129 is no exception. Even though the method of signal processing used allows very large improvements in signal-to-noise ratio to be achieved, the amount of noise contributed by the instrument itself affects its performance and limits the achievable improvement.

One convenient way of specifying the noise performance of an amplifier is to speak of its noise figure, which indicates the amount of noise the amplifier adds to the source thermal noise. Source thermal noise is used as the basis for comparison because it is completely predictable, always present, and is the least amount of noise which can possibly accompany any signal. Its value, in volts rms, is given by the following formula.

$$E_n = \sqrt{4kTBR_s} \qquad \text{IV-1}$$

where:

E_n = rms noise voltage within the bandwidth of the measurement.
k = Boltzmann's constant = 1.38×10^{-23} joules/kelvin.
T = absolute temperature in kelvins.
R_s = Resistance in ohms of the resistive component of the impedance across which the voltage is measured.
B = Bandwidth over which the measurement is made.

Mathematically expressed, noise figure can be stated as:

$$NF\ (dB) = 20 \log_{10} \frac{\text{Noise Voltage at the Output of the Amplifier}}{\text{That Portion of the Numerator Attributable To Source Thermal Noise}} \qquad \text{IV-2}$$

Noise figure is not constant but varies as a function of the source resistance, frequency, and temperature. When the loci of all points having the

same noise figure are plotted as a function of frequency and source resistance (temperature fixed), the result is a noise figure contour. A full set of contours completely specifies the noise characteristics of the amplifier over its working range. Figure IV-6 contains a full set of contours for a typical Model 129. The utility of these contours are, first of all, that they clearly indicate the best noise performance region in terms of operating frequency and source resistance, and secondly, that they allow one to directly compute the total noise accompanying the signal (amplifier noise and source thermal noise considered, other noise sources neglected). The relating formula is:

$$E_t = \sqrt{4kTBR} \times 10^{NF/20} \qquad \text{IV-3}$$

where E_t is the total noise referred to the input in volts rms and all other terms are as defined previously. Note that with a noise figure of 3 dB, the amount of noise contributed by the amplifier is 1.4 times the source thermal noise. At 1.4 times the thermal noise, the amplifier noise just begins to be noticeable. At lower noise figures, the amplifier for all practical purposes may be regarded as noiseless. Generally speaking, if one can operate anywhere inside the 3 dB contour, amplifier noise considerations may be neglected.

As critical as amplifier noise is in certain applications, it is nevertheless possible to overemphasize its general importance. For example, if the signal amplitude is significantly higher than the amplifier noise, the subject becomes purely academic. Similarly, if preamplification is provided ahead of the Model 129, with the result that the amplified source noise at the input to the Model 129 is far greater than the amplifier noise, there is little point in striving to operate inside the 3 dB contour of the Model 129. However, where a preamplifier is used, it is important that these same considerations be carefully evaluated for the preamplifier. In other words, when using a preamplifier, try to operate inside the 3 dB contour of the preamplifier. A quick check of Figure IV-6 followed by a computation of the total noise (Equation IV-3) should give one a realistic idea of the importance of amplifier noise considerations to the measurement at hand.

Where amplifier noise is a consideration, one should try to operate inside the 3 dB contour by appropriately adjusting the operating frequency or source resistance. The choice of operating frequency is usually determined by the type of sensor used and by the capabilities of the chopper, where one is used. Often the experimenter has some control over his choice of frequency and so can adjust things so that he is operating at the low noise end of the frequency range available to him.

The situation with regard to source resistance may be less flexible because the source resistance is usually determined solely by the type of sensor used. Once the commitment to a particular sensor has been made, it can be difficult to adapt the system to another one. Hence, in applications where noise is a potential problem, the choice of sensor should be made carefully and with full regard for the noise characteristics of the amplifier.

Two situations deserve special attention, the first being operation from a source resistance very much lower than optimum, and the second being opera-

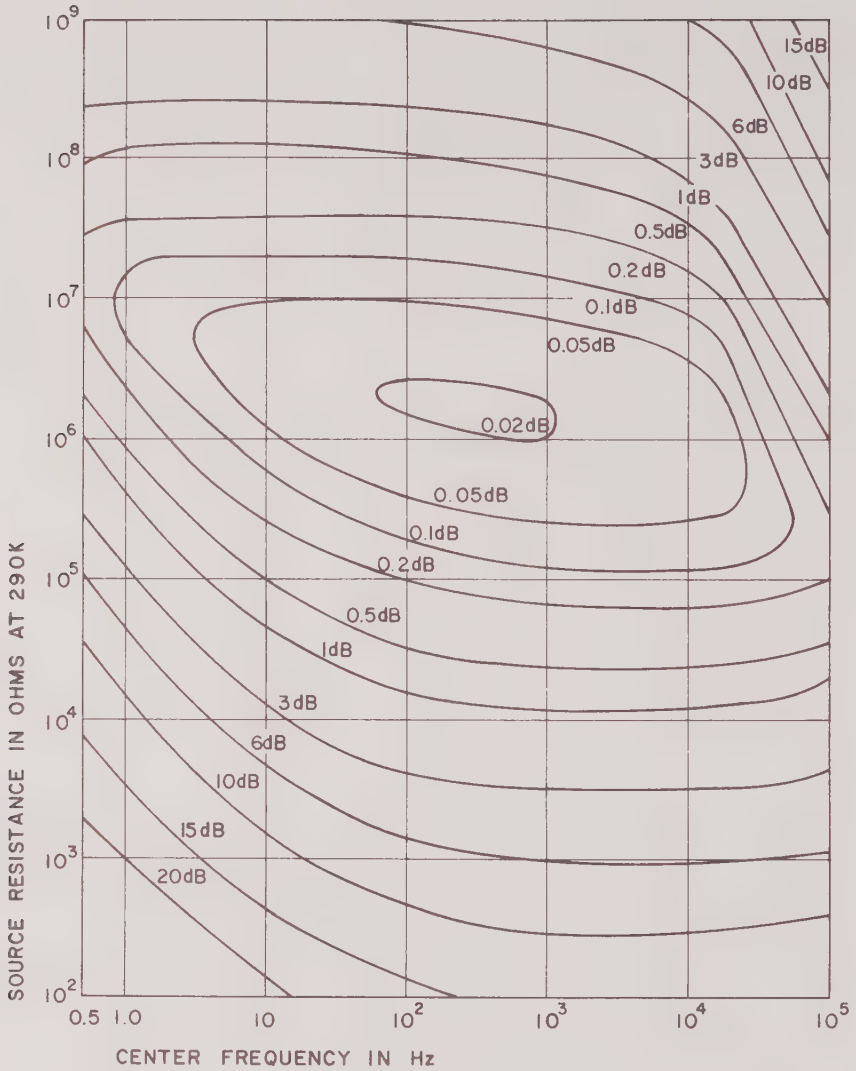


Figure IV-6. TYPICAL MODEL 129 NOISE FIGURE CONTOURS

tion from a source resistance very much higher than optimum. In either case, there may be a temptation to 'improve' the source resistance situation by the use of resistors. In the case of the low source resistance, one may wish to connect a resistor in series with the source. In the case of the high source resistance, one may wish to connect a resistor in parallel with the source. Unfortunately, neither approach to the problem does any good and, in fact, both will result in further degradation of the signal-to-noise ratio ahead of the lock-in amplifier. The series resistor adds its thermal noise to that already accompanying the signal. Although the amplifier shows a 'better' noise figure than before, it is only because the amplifier noise is now less relative to the thermal noise of the combined resistances (source plus series resistor). The signal is no larger (in fact, it may well be attenuated), the noise is greater, and the improved noise performance is illusory. Recall

that noise figure only relates amplifier noise to thermal noise, and does not denote the absolute value of amplifier noise.

Connecting a parallel resistor to lower a high source resistance has a similar effect. Even though the thermal noise does go down, the signal amplitude goes down even more. For example, if a source of resistance R were paralleled by another resistor of the same value, the signal amplitude would go down by a factor of two. However, the thermal noise would only be reduced to .707 of its initial value (thermal noise varies directly with the square root of the resistance), with a net degradation in signal-to-noise ratio.

In operating from low source resistances, however, one can usually improve the situation dramatically by using a transformer to raise the source resistance seen by the amplifier. The improvement one obtains with a transformer is real. The amplitude of both the signal and noise increases by the turns ratio. The source resistance increases by the square of the turns ratio, so that, by selecting the proper turns ratio, one can operate at a source resistance where the amplifier is essentially noiseless. For example, if one had a ten ohm source, one could use a 1:100 step-up transformer, in which case the amplifier would see a source resistance of 100 kΩ. At 100 kΩ the amplifier adds little additional noise. Even though the thermal noise of the transformer adds to that of the source, a very considerable improvement is usually achieved. PAR manufactures a line of suitable signal transformers, each designed for optimum operation over a given frequency range. Performance information can be obtained from the factory or one of its representatives.

However, if an external transformer is used, and if it is connected differentially to the Model 129, static charge can build up on the secondary and drive the Model 129 input stage into saturation. This happens because the high impedance of the input and the high inter-winding transformer resistance are not a sufficient discharge path. The way to prevent such a static charge buildup is to operate the Model 129 single-ended. The external transformer provides sufficient common-mode rejection so that nothing is lost by single-ended operation.

When working from a high source resistance, one could, in principle, use a transformer in an analogous manner to improve noise performance. Unfortunately, practical transformer design considerations usually prevent one from doing so. As a result, the options available to an experimenter working with a high source resistance device, such as a photomultiplier, are limited. Practically speaking, the best one can do is to make the load resistor as large as possible. The larger the load resistor, the less the shunting effect it will have, and the better the signal-to-noise ratio at the input of the amplifier will be. That this is so becomes clear when one recalls that the signal amplitude varies directly with the load resistance, while the thermal noise varies with the square root of the resistance.

Note that the entire preceding discussion of noise is based on comparing the noise generated by the amplifier with the source thermal noise. In many situations, other types of noise or interference may accompany the signal as well and could even dominate it. Where this is the case, the amplifier can only perform 'better' than the noise figure contours indicate because the

noise figures are based on a comparison of amplifier noise with the minimum possible noise which can accompany any signal, namely, the source thermal noise.

4.3 OPERATING THE MODEL 129

4.3A INTRODUCTION

Operation of the Model 129 is straightforward. In most instances, the operator simply connects the reference signal, waits for the REF UNLOCK light to go out, and then connects the signal to be measured. The Sensitivity and Phase controls are then adjusted as appropriate for the signal level and type of measurement being made. Should overload occur, the time constant is increased and/or the sensitivity is reduced as required to eliminate the overload. The reading can then be taken.

In many situations, achieving a successful measurement will depend not so much on critically adjusting the Model 129 controls as on taking the proper steps indicated by the preliminary considerations discussed in subsection 4.2. Factors such as proper grounding and operating inside the 3 dB contour are most important in making low level measurements of noisy signals.

4.3B REFERENCE CHANNEL

Reference Signal Requirements: An outstanding feature of the Model 129 is its unique reference channel circuitry which allows it to lock onto and track a wide range of possible reference input waveforms. Once locked on, the reference remains locked on, even if the reference input signal changes in frequency. There are no Reference Channel controls of any kind which must be adjusted for proper reference channel operation. Once the light goes out, all that remains is to adjust the Phase controls so that the Reference signal applied to the demodulator is at the proper phase relative to the signal to be measured. As stated in the specifications, the only requirements on the reference signal are that it swing at least plus and minus 50 mV with respect to its mean, that it cross its mean twice each cycle, and that it remain on each side of the mean for at least 100 ns. Sinewaves, square waves, triangle waves, and many others are all suitable. One waveshape which at first glance may seem to suffice, but which does not, is the very narrow low duty factor pulse. For example, suppose one intended to use as a reference signal the pulse train depicted in Figure IV-7A, that is, zero referenced pulses having an amplitude of 1 V, a duration of 1 μs, and a period of 1 ms. The mean of this signal would be about 1 mV, and the excursions relative to the mean would be +999 mV (1 V) and -1 mV (0 V). Thus, the individual pulses, even though they exceed the minimum excursion requirement on one side by some 950 mV, lack meeting the excursion requirement on the other side of the mean by a full 49 mV (50 mV required), with the result that the Reference Channel will not function properly. Thus, when using pulses as the reference input, take care that the excursions on each side of the mean will be great enough for proper triggering. In the example just cited, if the pulse duration were increased to 100 μs as shown in Figure IV-7B, the mean would increase to 100 mV, and the excursions (900 mV one side, 100 mV the other) relative to the mean would be more than adequate for proper triggering.

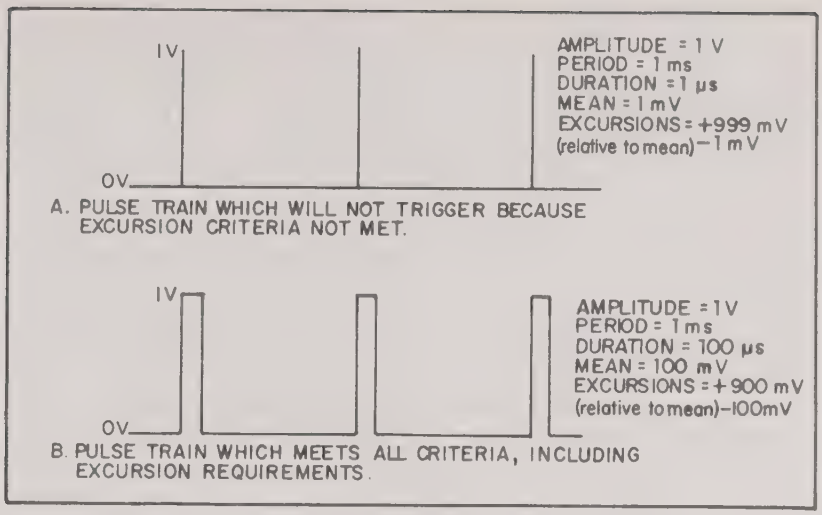

1V
0V
AMPLITUDE = 1 V
PERIOD = 1 ms
DURATION = 1 µs
MEAN = 1 mV
EXCURSIONS = +999 mV
(relative to mean) −1 mV
A. PULSE TRAIN WHICH WILL NOT TRIGGER BECAUSE EXCURSION CRITERIA NOT MET.
1V
0V
AMPLITUDE = 1V
PERIOD = 1 ms
DURATION = 100 µs
MEAN = 100 mV
EXCURSIONS = +900 mV
(relative to mean) −100mV
B. PULSE TRAIN WHICH MEETS ALL CRITERIA, INCLUDING EXCURSION REQUIREMENTS.

Figure IV-7. PULSE TRAIN AS REFERENCE DRIVE

Even though the Model 129 can accept and track a wide range of possible reference signals, it is nevertheless important that the reference signal used be relatively noise free. Any superimposed noise can cause many small zero crossings to occur in the region of the main waveform zero crossings, with the result that the Reference Channel momentarily 'sees' a much higher reference frequency than what is really there. When this happens, the reference 'lock' can be lost. Frequently, moderately noisy signals can be cleaned up sufficiently for satisfactory operation by interposing a single-section low-pass filter between the reference signal source and the Reference Input connector of the Model 129. On later instruments, space is provided for mounting the filter components on the Reference printed circuit board. Location of mounting holes is indicated opposite page VIII-4.

Switches: In addition to the Vector switch, which determines whether the Model 129 is to function as a lock-in amplifier or as a vector voltmeter, there are three other switches associated with operation of the Reference Channel. One of them, the f/2f switch, is located at the front panel. The other two are internal. The front panel switch determines whether the mixer will be driven at the frequency of the applied reference signal or at twice the frequency of the applied reference signal. The '2f' position is used for second harmonic studies. For normal operation, the switch is set to 'f'. To examine harmonics higher than the second, the operator has to supply a reference signal at the frequency of the harmonic to be measured. One should check the position of this switch before connecting the Reference signal; when the switch position is changed during operation, the reference channel will unlock, and time will be lost in waiting for it to lock on again. In most situations, the lost time would be but a few seconds and of little consequence. However, if one were operating at a low frequency, it could be lengthy.

The internal switches determine the lock-on range, either .5 Hz - 100 kHz or 5 Hz - 100 kHz. With these switches set to either FAST or SLOW, the unit

will lock onto reference signals in the frequency range of 5 Hz to 100 kHz without difficulty. However, only when the switches are set to SLOW will it lock onto reference signals which are below 5 Hz. The switches should be set to SLOW only for operation below 5 Hz, because the time to lock on is longer with the switch set to this position than when it is set to FAST. The photograph on page V-2 shows the location of these switches.

Detector Biasing: There is provision for detector biasing at the Reference Input by means of an internal network. The network is not provided but must be furnished by the operator according to the impedance and voltage requirements of his detector. The parts location diagram which faces page VIII-4 shows where to install the resistors.

Vector Switch and Vector Voltmeter Operation: The Vector switch determines whether the instrument is to function as a lock-in amplifier or as a vector voltmeter. For lock-in amplifier operation, the switch is left in the 2 PHASE position. For operation as a vector voltmeter, it is set to VECTOR, but only after making some other control changes as explained in the following paragraph. The SET position is a transition position in which the Phase meter circuitry is zeroed. Although it is never necessary to leave the switch in the SET position (the momentary contact which takes place as the switch is moved from 2 PHASE to VECTOR is sufficient to achieve the desired zeroing operation), there may be occasions where it is desirable to do so from the point of view of operating convenience.

To use the instrument as a vector voltmeter, one begins in the same manner as for lock-in operation. The Vector switch is set initially to 2 PHASE, the reference and input signals are connected, and the Sensitivity and Output Expand switches are adjusted as appropriate for the input signal and noise amplitudes. These preliminary considerations attended to, the next step is to set the Phase Quadrant switch as required to obtain a positive deflection on the Magnitude (lefthand) panel meter. The amplitude of the deflection does not matter. Only the polarity is important. Once this is done, set the Phase (right-hand) Time Constant and Output Expand switches as required by the change in function these switches undergo when the instrument is transferred to vector voltmeter operation. Instead of providing demodulator output filtering and output expansion respectively, as they do in lock-in amplifier operation, these two controls work together to determine the stability and response time of the phase meter circuitry. As a general rule, for stable operation at frequencies above 5 Hz, the Phase Time Constant switch should be set to 10 SEC. Between 5 Hz and 1 Hz, it should be set to 30 SEC, and below 1 Hz, it should be set to 100 SEC. The Output Expand switch should be set to X100, except when operating at the extreme low frequency, .5 Hz, where it should be set to X10. It will frequently happen that the Overload light will come on when the Output Expand switch is set to X100. This overload is of no consequence unless a recorder or other measuring device is connected to the Phase output. However, the overload can be prevented by setting the Vector switch to SET just before increasing the output expansion. Only after the Phase Time Constant and Phase Output Expand switches have been set for vector and voltmeter operation, should the Vector switch be set to VECTOR, thereby completing the transfer to vector voltmeter operation. At that time the Magnitude meter will commence to indicate the magnitude of the input signal (the Magnitude Time Constant and Output Expand switches function

the same as in lock-in amplifier operation) and the Phase meter will indicate the signal's phase. It should be noted that the response time is much faster (assuming a full scale input signal) than one would expect from the selected Phase 'Time Constant'. As explained above, the function of the right-hand Time Constant switch in Phase operation is to stabilize the phase meter circuitry and not to determine the response time in a manner directly related to the switch setting.

There are two situations where it may be desirable to use Phase Time Constant and Output Expand settings other than as indicated above. The first is where the input signal is so noisy as to give unacceptably large fluctuations in the phase meter indication. The other is where the input signal amplitude, expressed as a function of the Magnitude meter full scale sensitivity, is very small. If a noisy signal causes large fluctuations in the Phase meter indication, increased smoothing can be obtained by selecting a larger 'Time Constant', or by selecting a lesser degree of output expansion. The Phase meter sensitivity remains ±100° regardless of the setting of the Phase Output Expand switch.

A characteristic of the Phase meter circuitry is that its response time depends on the amplitude of the input signal. With signals on the order of full scale to as small as a few percent of full scale, the response time is adequately rapid using the control settings stated earlier. However, with very small input signals, the response can become very slow. Again the operator has two options for speeding the response. He can increase the Output Expansion or decrease the 'Time Constant'. In most instances, the Output Expansion will already be set to X100, leaving the 'Time Constant' as the only variable. With large input signals, for good stability it is necessary that one use one of three 'red' settings (10 SEC, 30 SEC, or 100 SEC). However, with very small signals, one is no longer limited to using these settings, and the 'Time Constant' can be shortened considerably to achieve the desired rapid response. If it is set too low, instabilities will develop as will be noted from observing the panel meter Overload light, and, if things really get out of hand, the Reference Unlock light. (In the event that the reference lock is lost, it can be recovered by increasing the time constant and setting the Vector switch to SET or 2 PHASE. When the Unlock light extinguishes, one can return to vector voltmeter operation.) However, it should always be possible to achieve a good rapid response time well short of the instability point. The phase of signals having a magnitude as small as .01% of full scale, even if accompanied by noise, can be quickly and simply measured in this manner. The ultimate in slowed response takes place when the input signal is disconnected. With zero input signal, the phase loop response time goes to infinity, and the phase meter simply 'holds' the existing setting.

In addition to the earlier mentioned technique of setting the Vector switch to SET prior to increasing the Output Expansion to prevent an overload indication, there is one other situation where use of the SET position can prove convenient. Suppose one were measuring a signal under conditions which yielded a large negative Phase indication but with a rather slow phase meter response time. Further suppose that the experimental parameters change in such a manner as to cause a large positive phase meter indication. The time required for the phase meter to go from a large negative indication to a

large positive indication (slow response conditions assumed) can be shortened considerably by momentarily setting the Vector switch to SET. The meter will instantly go to '0', presumably half way to the desired setting. The Vector switch is then returned to VECTOR, and the Phase meter indication continues upscale until it reaches the proper indication. This momentary use of the SET position of the Vector switch can cut a measurement time in half. However, in the vast majority of measurements, the response time is so fast as to make the need for this operating 'trick' highly unlikely.

Phase Controls: A high resolution potentiometer covering the range of 0-to-100 degrees works in conjunction with a Quadrant switch to determine the phase of the synchronous detection process with respect to the phase of the applied reference signal. Expressed differently, the Phase controls set the phase of the reference drive to the two demodulators, with the reference drive to the Quadrature demodulator leading by 90° the reference drive to the In Phase demodulator.

Both demodulators provide a dc output which is proportional to the amplitude of the input signal and which varies with the cosine of the angle between the input signal and the reference drive to the demodulators. Since the reference drives to the two demodulators are 90° out of phase, the instrument allows the In Phase and Quadrature components of the input signal to be measured simultaneously. The In Phase meter indicates the amplitude of the signal component which leads the reference signal by the angle set by the Model 129 Phase controls. The Quadrature meter indicates the amplitude of that component which leads by an additional 90°.

Where the phase is to be set for maximum indication on one of the meters when monitoring a noisy signal, it could happen that meter fluctuations due to noise will make it difficult to find the setting which gives the desired maximum. If this happens, it will usually prove more accurate and expedient to adjust for null on the other meter.

The situation is somewhat different for vector voltmeter operation. First of all, the magnitude reading is completely independent of the setting of the Phase controls, and the phase meter indicates the phase of the input signal with respect to the signal applied to the Reference Input connector. However, the phase indicated by the meter must be added to that indicated by the setting of the Phase dial and Quadrant switch. Additionally, there is a restriction on the maximum phase reading. For a phase reading to be valid, the total phase (meter plus dial but not including the quadrant switch) cannot exceed 180°.

The absolute accuracy and resolution of the Phase controls are stated in the specifications. Figure IV-8 shows the typical accuracy of the Phase controls. Additional phase shifts are introduced in the Signal Channel at the frequency extremes. Also, the HI-PASS and LO-PASS filters can affect the signal phase. If the unit in question is equipped with the Tuned Amplifier modification, there may be additional phase shift if the tuned amplifier is not tuned to exactly the input signal frequency. This total phase offset can be easily measured by operating the instrument as a vector voltmeter while applying a noiseless signal to both the Signal and Reference inputs. The Reference Input signal is frequently suitable for this purpose. Any result-

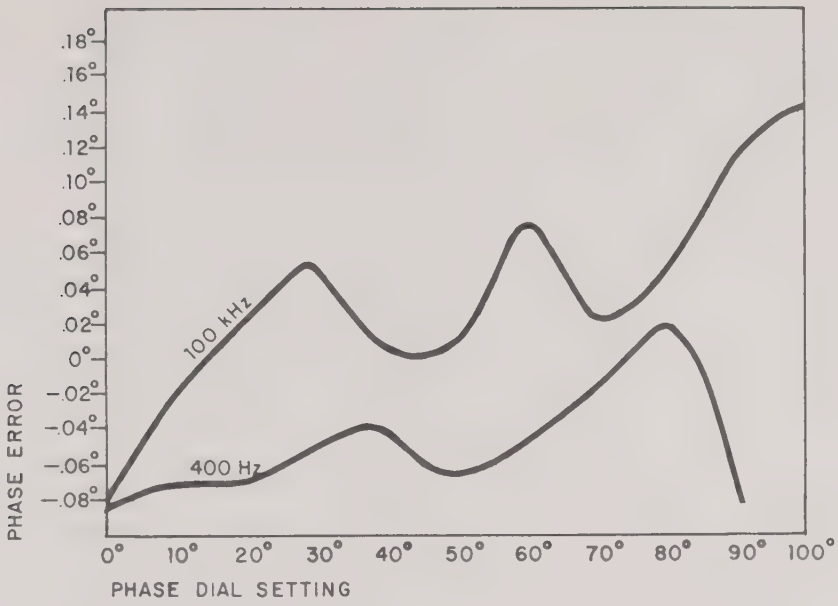


Figure IV-8. TYPICAL ACCURACY OF THE PHASE CONTROLS

ing phase indication is simply the offset to be subtracted from phase readings made on 'real' signals produced by the experiment.

Note that the phase resolution can be read with greater ease by adjusting the Phase controls for 'null' on the Phase meter, and then reading the phase from the Phase dial, taking the Quadrant switch setting into account as well.

Reference Monitor Connector: An optional Reference Monitor output can be provided at a rear-panel connector. The Reference Channel output is available at this connector. This signal is a square wave taken from ahead of the Mixer but after the Phase Control circuitry, and so is at the frequency of the applied reference signal (twice the frequency in the case of '2f' operation) and at the phase set with the Phase controls. TTL logic levels are employed. Logic '0' = 0.2 V ±0.2 V and Logic '1' = +4.0 V ±1 V.

4.3C SIGNAL CHANNEL

Introduction: Operation of the Signal Channel controls is straightforward. The Input Selector is set to 'A', 'A-B', or '-B' as appropriate, the Sensitivity switch is set for as near full-scale output as possible, and the filters are used if necessary to narrow the bandwidth ahead of the Mixer. A further discussion of these topics follows.

Input Selector switch: With this switch set to 'A', the signal applied to the 'A' Input is processed by the instrument. Signal applied to the 'B' Input is dead-ended. Similarly, when the switch is set to '-B', the situation is the same except that the roles of the 'A' and 'B' inputs are reversed. Another difference is that the 'B' Input is 180° out-of-phase with respect to

the 'A' Input. In other words, if a signal which yields positive output meter deflection when applied to the 'A' Input is applied to the 'B' Input, an equal but negative reading will be obtained. In the 'A-B' position, the instrument operates differentially, that is, only the difference between the signals applied to the two inputs is processed and read out. As discussed in Subsection 4.2E, it may be advantageous to operate differentially, even when processing signals from a single-ended source.

Sensitivity and Output Expansion: When the Output Expand switch for a given output is set to X1, the instrument sensitivity to the measured component (in phase or quadrature) is directly given by the setting of the Sensitivity switch. This sensitivity can be increased by a factor of ten or one hundred by setting the appropriate Output Expand switch to X10 or X100 respectively. Thus the Output Expand switches give the operator the option of separately setting the In Phase and Quadrature sensitivity of the instrument.

In addition, they offer a means of increasing the overload capability. As indicated in the specifications, the overload capability (defined in the specifications) varies directly with the output expansion. Whereas the overload tolerance is 2X with the Output Expand switches set to X1, it increases to 20X with a setting of X10 and 200X with a setting of X100. However, this increased overload capability is gained at the expense of increased dc drift at the output. It should be noted, however, that the noisy signals which necessitate output expansion settings of X10 or X100 generally cause enough output fluctuations to make the increased drift of little consequence. Optimum, in terms of the best tradeoff of dc stability for noise tolerance, is obtained when operating with the least possible output expansion consistent with achieving the maximum possible ac sensitivity without overload. A suitable procedure for achieving this 'optimum' follows.

(1) Begin with reasonably high time constant settings, perhaps .3 SEC or 1 SEC, and with the Sensitivity switch set several steps clockwise relative to the expected signal level. The Output Expand switches should be set to X1.

(2) Begin rotating the Sensitivity switch counterclockwise. If the signal is relatively noise free, it will be possible to adjust the Sensitivity switch to where a good upscale meter indication is obtained on one (perhaps both) of the meters without any overload indication developing. The operator can then optimize the Phase (generally by adjusting the Phase controls for maximum on one of the meters (usually the In Phase meter), and take his reading.

(3) If, however, an overload indication occurs before the 'proper' sensitivity setting is obtained, appropriate remedial action will be required, as follows.

    (a) Try increasing the time constant to be sure that transients are not overloading the dc amplifiers. If this doesn't work, reset the Time Constant switches back to their original setting (.3 SEC or 1 SEC).

    (b) If the Input Filters are set to MIN and MAX, try setting them so

that they filter out the interference above and below the signal frequency. The tuned amplifier can be used to achieve the same goal in instruments equipped with the Tuned Amplifier Modification.

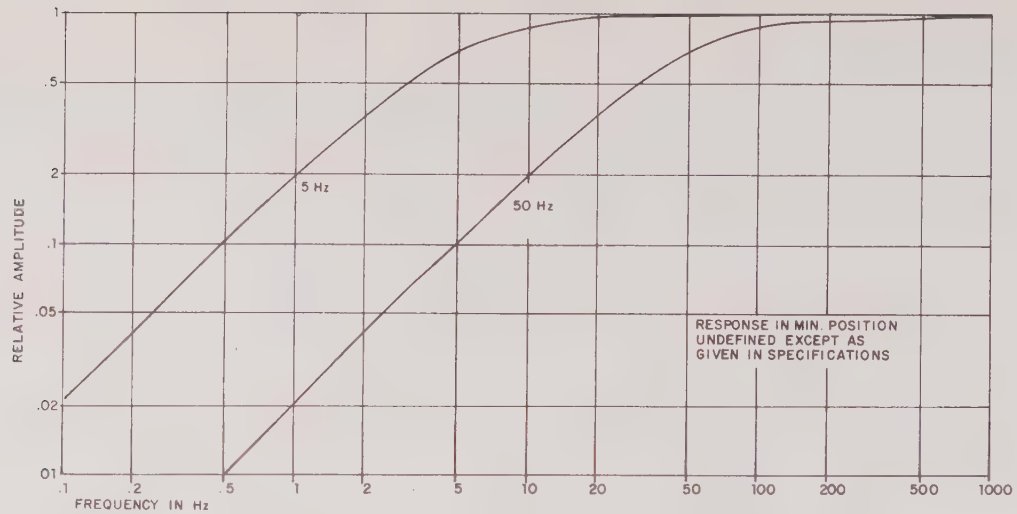
(c) If the overload indication still persists, begin increasing the output expansion to the degree required. When the overload light goes out, again rotate the Sensitivity switch as required to get the maximum meter deflection without overload. By proceeding in this manner, it should be possible to obtain a good up-scale reading without overload.

It may happen that the final meter deflection obtained by this method is less than one would like to have for making an accurate reading. The solution to this problem may be to simply increase the output gain and decrease the sensitivity. The greater number of steps provided by the Sensitivity switch allows the desired value of system gain to be achieved in this manner.

For example, suppose, in a given measurement, that a Sensitivity switch setting of '2.5 mV' resulted in an overload indication, with the result that the switch was initially set to '10 mV'. With the 10 mV sensitivity and an Output Expand setting of X1, the signal produced a barely perceptible deflection of the panel meter. With the Output Expand switch set to X10, the meter deflection could be read and was found to be 12% of full scale. This is still a relatively low reading, and greater accuracy would result if a higher meter deflection were obtained. However, an Output Expand switch setting of X100 would give 120%, an off-scale reading. The solution is to go ahead and set the Output Expand switch to X100, and at the same time to set the Sensitivity switch to '25 mV'. The net effect of these changes would be to give a meter deflection of 48%, high enough for a good accurate reading. With sensitivity setting of 25 mV and X100 output expansion, the net sensitivity of the instrument is 250 μV full-scale giving a signal amplitude of 120 μV.

Hi-Pass and Low-Pass Filters: The function of these filters is to eliminate as much interference and noise as possible while having minimal effect on the signal of interest. In using the filters, it is important to take their effect on the signal of interest into account. Figures IV-9 and IV-10 show the amplitude and phase characteristics of these filters as a function of switch setting and frequency. To find the net effect in a region where both filters affect the signal, multiply the amplitude transfer fractions and add the phase shifts. Use of the MIN. and MAX. positions simultaneously provides a flat response curve over the full operating range of the instrument (see specifications).

In certain applications, the operator might like to have other '3 dB down' frequencies than those provided. This can be done by changing the value of some internal capacitors. Each of the two filters has a separate capacitor for each of the three switch positions. The capacitors which determine the MIN and MAX response characteristics should not be changed. The other two can be. The Parts Location Diagram opposite page VIII-2 can be used to identify these capacitors. Schematically, they are shown on page VIII-3. In the case of the Low Pass filter, the relationship between capacitance and 3 dB down frequency is given by:



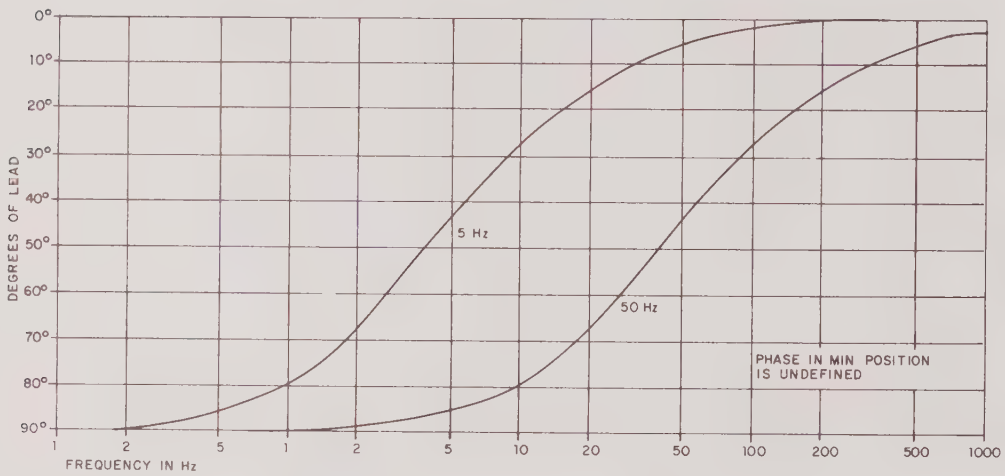


Figure IV-9. AMPLITUDE AND PHASE CHARACTERISTICS OF HI-PASS FILTER

$$C = 1 \div (6.3 \times (1.6)^2 \times f_{3dB}) \qquad \text{IV-4}$$

For the Hi Pass filter, it is:

$$C = 1 \div (6.3 \times (6.4)^2 \times f_{3dB}) \qquad \text{IV-5}$$

where (for both formulas):

C = the capacitance in microfarads, and
f_{3dB} = the desired input 3 dB down frequency.

4.3D OUTPUT CHANNEL CONTROLS

Filters: The primary function of the Output Channel is to act as a low-pass

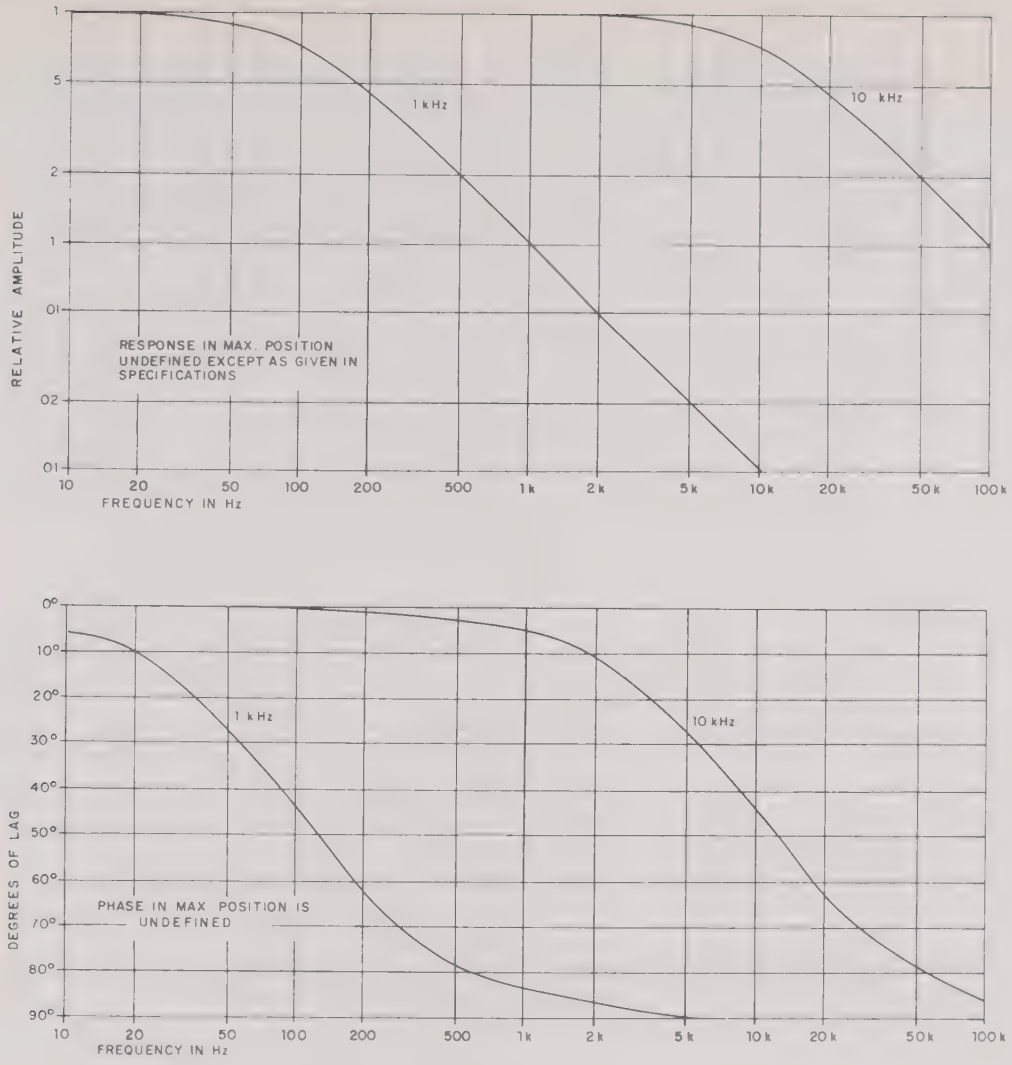


Figure IV-10. AMPLITUDE AND PHASE CHARACTERISTICS OF LOW-PASS FILTER

filter and eliminate any ac components at the output of the demodulators. Inasmuch as only dc modulator output represents the signal of interest (any ac results from noise), an improvement in signal-to-noise ratio is obtained. In principle, the signal-to-noise ratio can be improved to any arbitrary degree simply by making the filter time constant long enough. Practical considerations, however, generally set the limit to what can be achieved. The improvement in signal-to-noise ratio varies with the square root of the time constant. As a result, the measurement times rapidly become lengthy as the time constant is increased to obtain better signal-to-noise ratios. As a practical guide, the correct filtering time constant is the one which reduces the noise to an 'acceptable' level.

Two separate filters are provided for each channel, one variable and the other fixed. The variable filter allows time constants from 1 ms to 100 s to be

selected, in addition to MIN (time constant about .5 ms) and EXT. (time constant determined by external capacitors connected to rear-panel socket). The fixed filter has a time constant of one second. Both are single section filters having a 6 dB/octave rolloff. The filters have an accumulative effect as shown in Figure IV-11. Curve A shows the frequency response of the Output filter alone. With a one second time constant, the filter corner frequency is .16 Hz. Curve B shows the frequency response of the variable filter for three different settings, 10 SEC, 1 SEC, and .1 SEC. Curve C shows the resultant net filtering effect due to the interaction of the filters at each of the three combinations. The response is flat to the lowest corner frequency, where it starts down at 6 dB/octave. Beginning at the second corner frequency, the rolloff rate is 12 dB/octave. Generally speaking, the variable filter is set for 'acceptable' output noise. In many instances, there will be no need for the second filter. However, it is particularly useful when a recorder is being used in that it significantly reduces the recorder 'jitter'. Adjusting the instrument controls will generally be easier with the fixed one second filter OUT.

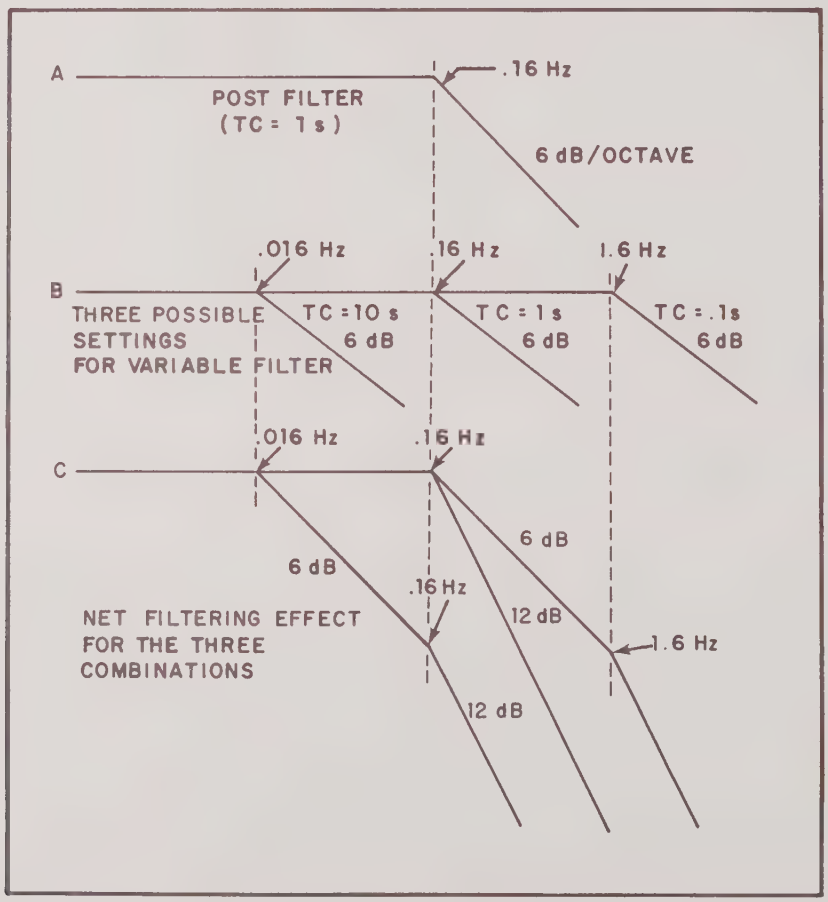


Figure IV-11. INTERACTION OF OUTPUT FILTERS

The equivalent noise bandwidth of a single-section 6 dB/octave filter is $\sqrt{1/4TC}$. Its rise time from 10% to 90% of full amplitude is 2.2 TC (0% to 95% is 3 TC). If the variable filter is set to one second and the second filter is 'in', the effect is the same as if one had a single two-section filter with a 12 dB/octave rolloff. The equivalent noise bandwidth of this filter would be $\sqrt{1/8TC}$ and the 10% to 90% rise time would be 3.3 TC (0% to 95% = 4.8 TC). When both filters are used but the variable filter is not set to one second, the relationship defining the equivalent noise bandwidth and rise time as a function of time constant is more complex. For all practical purposes, if the time constant of one is a factor of three or more longer than the other, the one with the longer time constant dominates and the single section expressions using the longer time constant characterize the rise time and equivalent noise bandwidth reasonably well. Nevertheless, even though the second filter may do relatively little to further reduce the equivalent noise bandwidth with a long variable time constant setting, its effect in smoothing a recording can be significant.

With the Variable Time Constant switch set to EXT, intermediate time constant values or time constants longer than 100 seconds can be obtained by connecting an external capacitor between pins eight and nine (In Phase) and between pins four and six (Quadrature) of the 11-pin socket at the rear panel. The formula relating the capacitor value and time constant is: C = TC/100 μF. Any low-leakage film capacitors rated at 50 V or higher can be used. Do not use electrolytic or tantalum capacitors.

When the instrument is operated as a vector voltmeter, the Magnitude output filters, both variable and fixed, have exactly the same function as for lock-in amplifier operation. However, in the case of the Phase 'Time Constant' switch, the function is entirely different. Instead of providing filtering and affecting the output response time to the degree indicated by the Time Constant switch setting, the filter circuits selected by the Time Constant switch determine the stability of the phase measuring circuits as explained under Vector Switch and Vector Voltmeter Operation on page IV-12. The fixed one second filter serves mainly to provide recorder smoothing, the same as in lock-in operation.

Output Expand Switches: These switches have two functions. First of all, when the instrument is operated as a lock-in amplifier, they allow the gain of the two channels to be independently set. Secondly, they give the operator the option of trading off overload capability for output dc stability so that the instrument's overload/drift performance can be optimized for any given input signal-to-noise ratio. This latter function is discussed in some detail under Sensitivity and Output Expansion, page IV-16.

When the instrument is operated as a vector voltmeter, the situation is somewhat different. Although the Magnitude Output Expand switch still works in conjunction with the Sensitivity switch to determine the overall instrument sensitivity and overload tolerance, the function of the Phase Output Expand switch is entirely different. Its function in vector voltmeter operation is to work in conjunction with the Phase Time Constant switch to determine the response time and stability of the Phase circuitry. The Phase Output Expand switch should always be set to X100 during vector voltmeter operation, except when greater noise rejection is required, or when operating at the extreme

low frequency, 0.5 Hz, where the switch should be set to X10.

Offset: The ten-turn dial and its associated polarity switch allow calibrated offsets of up to ten times full scale to be applied with Output Expand settings of X10 or X100, and up to two times full scale with Output Expand settings of X1. This feature, in addition to allowing small amplitude variations in a signal to be expanded and examined in detail, allows a signal amplitude to be read with greater resolution than is possible with the panel meter alone. For example, suppose one had a meter indication to the right. To read the amplitude with the greatest possible resolution, the polarity switch would be set to '+' and the dial adjusted for 'null', at which time the signal amplitude could be read directly from the dial. It should be noted that the Quadrature/Phase Offset dial is disabled in vector voltmeter operation.

The following example illustrates how the Zero Suppress feature can be used to read signal amplitude variations. Suppose one had a 70 μV signal. Assuming this signal were measured on the 100 μV sensitivity range with X1 Output Expansion, the resulting meter indication would be 70% of full scale. To examine small variations in this signal, one would first set the polarity switch to '+' (assume initial meter indication were to the right), followed by adjusting the dial for null. The dial setting required would be 0.70 and the meter sensitivity would be ±100 μV with respect to the 70 μV ambient level. A recorder connected to the output would allow the amplitude variations as a function of some experimental parameter to be recorded.

Because of the Offset dial range, ±10 times full scale (2 times full scale with X1 Output Expansion), the sensitivity of the measurement could be greatly expanded. In the example at hand, the Output Expand switch could be set to X10. The signal amplitude (70 μV) would be less than ten times full scale (10 X 10 μV = 100 μV) and so would fall within range of the Offset dial. If the dial were adjusted for null (setting 7.00), the meter would read ±10 μV full scale with respect to the 70 μV ambient signal level.

Outputs: There are two parallel outputs for each channel, a front-panel output and a rear-panel output. The output resistance is 600 ohms and full scale output is ±1 V, which corresponds to ±full-scale deflection of the panel meter. At the front panel, the output is provided at a BNC connector. At the rear panel, it is applied to one of a pair of binding posts. The second (black) binding post is ground. These binding posts are spaced to accept a standard double-banana connector. It is frequently more convenient to use the rear-panel output when using a strip-chart recorder as the readout device.

Mixer Monitor Output: An optional Mixer Monitor output is provided at the rear panel. The signal applied to this output is taken directly from the output of the Mixer and before any filtering. Figure IV-12 illustrates the Mixer output corresponding to in-phase and quadrature signals respectively. If the signal and reference inputs to the Mixer are either in phase or 90° out-of-phase, the signal at the output of the Mixer will be as shown. For signals 180° out-of-phase, the Mixer output will be the inverse of the in-phase output, and for signals 270° out-of-phase, the output will be the inverse of the 90° output. Taking the maximum possible area which can be en-

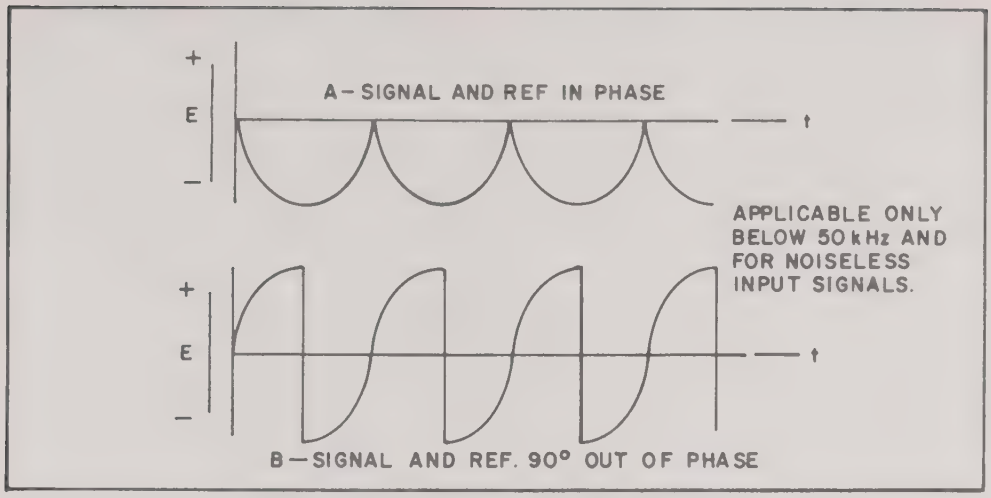


Figure IV-12. MIXER OUTPUT FOR IN-PHASE AND QUADRATURE SIGNALS

closed by one cycle (one polarity) as a unit output, the output averaged over a cycle for any Mixer input phase relationship will be the unit output times the cosine of the angle between the input and reference signals.

The cosine response depends on the sinusoidal nature of the input signal. If the signal were a square wave and the tuned amplifier were not used, the Mixer output would vary linearly with the angle between the signal and reference inputs. Nevertheless, maximum output would still be at 0° and 180°, and zero output would be obtained at 90° and 270°.

It might be mentioned that the waveforms illustrated in Figure IV-12 apply only at frequencies below 50 kHz and with a noise-free input signal. At higher frequencies, switching spikes become visible and some Mixer filtering effects become evident. Even relatively small amounts of noise accompanying the signal could completely obscure it at the Mixer output, especially if one were operating without the tuned amplifier.

4.4 HARMONIC SENSITIVITY

Coherent signals which are harmonically related to the input signal fundamental influence the output indication and must be taken into account when processing non-sinusoidal signals. Although the output meters of the Model 129 are rms calibrated, the instrument itself is average responding and so provides 'true' readings only when the input signal is a sinewave. The response of the demodulators to any given harmonic is exactly proportional to the amplitude of the corresponding component of the reference drive to the demodulators. It follows that, in that the reference drive is a square wave (this is true regardless of the shape of the waveform applied to the Reference Input connector), the demodulators have an odd harmonic response of 1/n, where n is the order of the harmonic. It also follows that there should be no response at all to even harmonics, since they do not contribute to the square wave. Unfortunately, no square wave is perfectly symmetrical, and any resi-

dual dissymmetry gives the demodulators a net response to even harmonics. In the case of the Model 129, the worst case even harmonic response of the demodulators is about 1%.

If the Model 129 is operated with a flat response, that is, without the input filters or the tuned amplifier, all of the input harmonics which fall within the passband of the instrument are applied to the demodulators without attenuation or phase shift. However, because the reference inputs to these demodulators are in quadrature, the phase of the various harmonics determines the degree to which each responds to them. In the case of a square wave input signal, which consists of the fundamental and its odd harmonics only, all of the harmonics are in phase with the fundamental, that is to say, each zero crossing of the fundamental is coincident with a zero crossing of each harmonic. As a result, assuming the Phase controls are adjusted for maximum In Phase meter deflection, these harmonics arrive at the In Phase demodulator in phase with the reference drive to the In Phase demodulator and so add to the output of the In Phase channel. At the Quadrature demodulator, both the fundamental and the odd harmonics arrive in quadrature with the reference drive to that demodulator and there is no Quadrature output.

The situation is somewhat different if the input filters are used or if the instrument has the tuned amplifier modification. Consider the case for the tuned amplifier, which in addition to attenuating the harmonics, phase shifts them as well. Even the third harmonic is shifted nearly 90°, and all higher harmonics can be considered to be shifted a full 90°. Recall that a square wave consists of a fundamental together with its odd harmonics, with the amplitude of each being 1/n of the fundamental amplitude, where n is the order of the harmonic. Assume for the moment that we are interested in the effect of the third harmonic, since it is the largest, having an amplitude 1/3 that of the fundamental. The tuned amplifier (Q of 5) will phase shift the third harmonic approximately 90° and attenuate it to about 1/15 of its input amplitude. Thus the amplitude of the third harmonic at the output of the tuned amplifier will be about 1/45 that of the fundamental (1/3 x 1/15).

Next consider the demodulator response, which, in the case of the third harmonic, is 1/3 the fundamental response. Thus, the overall system response to the third harmonic is 1/135 of its response to the fundamental, independent of phase considerations. However, because of the 90° phase shift introduced by the tuned amplifier, the third harmonic (and all higher odd harmonics) arrives at the In Phase demodulator in quadrature with the fundamental and in quadrature with the reference drive, and the demodulator does not respond to it. The In Phase demodulator effectively 'sees' only the fundamental frequency component, the amplitude of which can then be read from the In Phase meter. At the Quadrature demodulator on the other hand, the harmonic arrives in phase with the reference drive to that demodulator, and a quadrature amplitude of a little less than 1% is obtained. One might expect that such a low signal level would go unnoticed, but, if the Quadrature Output Expand switch were set to X100, nearly full-scale meter deflection would occur.

Practically speaking, this discussion is largely academic as far as operating the instrument goes. The difference between the Phase control setting which gives the 1% Quadrature meter response and that which gives much larger Quadrature meter indications (either polarity) is so small that its effect on the

In Phase indication is virtually indistinguishable. When the Phase dial is adjusted for '0' Quadrature meter indication, the In Phase meter will read maximum for all practical purposes. This simply reflects the fact that the amplitude of a cosine wave varies as a function of phase much more rapidly in the region of a zero crossing than it does at a peak.

The following examples should help to summarize all of the preceding into some useful numbers. With a pure sinewave input, the instrument measures the rms amplitude of the input signal. This is true whether or not the tuned amplifier or input filters are used. If, of course, the signal frequency is such as to be attenuated by the tuned amplifier or one of the input filters, this attenuation will have to be taken into account.

If the input signal is a square wave, and neither the tuned amplifier nor the filters is 'in', the instrument will read 'high' due to the harmonic response. A square wave having a pk-pk amplitude of 1.8 times the selected rms sensitivity will yield full-scale output. In other words, if one were operating with the Sensitivity switch set to 100 mV, a 180 mV pk-pk input square wave would yield full-scale output. On the other hand, if the tuned amplifier were employed, the In Phase demodulator (assuming Phase controls properly adjusted) would only respond to the fundamental frequency component of the input square wave, with the result that a square wave having a pk-pk amplitude of 2.22 times the selected rms sensitivity would yield full-scale output. For example, if one were operating with the Sensitivity switch set to 100 mV, a 222 mV pk-pk square wave would yield full-scale output.

With input signals other than square waves, the response would be different, and would have to be separately determined for each case.

These same considerations apply to the magnitude channel reading when the instrument is operated as a vector voltmeter.

There is one application where one has to be concerned with the 'subharmonic response' of the Mixer, and that is when measuring second harmonics using the 2f mode. When the instrument is operating in this mode, it has a fundamental response (the fundamental can be thought of as a subharmonic of the signal of interest, the second harmonic) of about half a percent. Hence, for accurate second harmonic measurements, it is essential that the fundamental be attenuated ahead of the Mixer. One convenient way of doing this is to use the optional tuned amplifier. By operating in the Notch mode with the Notch tuned to the frequency of the fundamental, the fundamental is reduced to a negligible level with only 1% loss in the amplitude of the second harmonic. It follows that the Tuned Amplifier can also be used to good advantage when measuring harmonics higher than the second as well.

4.5 INTERFACE CONNECTOR

An 11-pin Interface connector is provided at the rear panel. Table IV-1 indicates the function of each pin. Observing the connector from outside the instrument, the pins are counted counterclockwise from the key.

4.6 BATTERY OPERATION

Battery operation of the Model 129 Lock-In Amplifier may be necessary where

Pin	Function
1	Chassis Ground.
2	+15 V Out (load limit = 20 mA).
3	-15 V Out (load limit = 20 mA).
4	Quadrature External Time Constant Capacitor.
5	-20 V to -30 V In (battery operation, 300 mA req.)
6	Quadrature External Time Constant Capacitor.
7	+20 V to +30 V In (battery operation, 300 mA req.)
8	In Phase External Time Constant Capacitor.
9	In Phase External Time Constant Capacitor.
10	No Connection.
11	No Connection.

Table IV-1. INTERFACE CONNECTOR PIN ASSIGNMENTS

no ac power is available, or as a last resort where power line interference is a problem. Battery operation of the Model 129 is straightforward because the points to which one must gain access are provided at the rear-panel 11-pin socket. Two batteries are required, one to supply +20 V to +30 V (300 mA) and the other to supply -20 V to -30 V (300 mA). The positive power source should be connected to pin 7. The negative power source should be connected to pin 5. Ground for both is at pin 1. It is generally a good idea to fuse the battery lines external to the instrument, and to provide an ON/OFF switch as well. The front-panel ON/OFF switch does not control the instrument's power when it is operated from batteries. Nevertheless, the battery drain is minimized if the front-panel power switch is kept in the OFF position because of the switch's built-in light. Keep the line cord disconnected during battery operation.

4.7 OPERATION WITH THE INTERNAL REFERENCE OSCILLATOR

4.7A INTRODUCTION

In some applications, the experimental apparatus does not generate a suitable reference output, but is itself capable of being driven by an external signal source. To facilitate use of the Model 129 in such applications, an internal reference oscillator modification is provided. With this modification installed, a signal of variable frequency and amplitude is generated by a sine-wave oscillator inside the Model 129. The output of this oscillator, in addition to being provided at a rear-panel connector for easy routing to the experiment, can be applied internally to the Reference Channel so that it is directly driven by the same signal as drives the experiment. It is also provided at the front panel Reference INPUT connector at an impedance of 10 kΩ for monitoring purposes only. The Phase controls remain fully functional, allowing the internal reference signal and the information signal from the experiment to be phased properly at the demodulators.

4.7B OPERATION

Operation of the internal oscillator is straightforward. Two openings in the

rear panel of the Model 129 give access to the adjustments which set the amplitude and frequency. The frequency adjustment allows the frequency to be varied over about a 3:1 range, with the actual range spanned depending on the value of two capacitors mounted on the oscillator board. Table IV-2 indicates the frequency range of the adjustment as a function of the value of these capacitors. The capacitors can be easily changed; they are held by spring-loaded special clips which release the component lead when pressed downwards. The capacitors should be low-leakage types matched to within 5%. Mylar, polystyrene, polycarbonate, teflon, and other film capacitors rated at 50 V or better are suitable from 10 μF to 2 nF. Below 2 nF, mica capacitors are recommended. Do not use electrolytic, tantalum, or ceramic capacitors. Because the oscillator board plugs into the main board, one must remove the top cover of the Model 129 to change the capacitors.

Approximate Freq. Range	Capacitor Value ±5%
0.53 Hz to 1.58 Hz	10 μF
1.06 Hz to 3.2 Hz	5 μF
2.7 Hz to 7.9 Hz	2 μF
5.3 Hz to 15.8 Hz	1 μF
10.6 Hz to 32 Hz	500 nF
27 Hz to 79 Hz	200 nF
53 Hz to 158 Hz	100 nF
106 Hz to 320 Hz	50 nF
270 Hz to 790 Hz	20 nF
530 Hz to 1.5 kHz	10 nF
1 kHz to 3.2 kHz	5 nF
2.7 kHz to 7.9 kHz	2 nF
5.3 kHz to 15 kHz	1 nF
10 kHz to 32 kHz	500 pF
27 kHz to 79 kHz	200 pF
53 kHz to 130 kHz	120 pF

Table IV-2. FREQUENCY RANGE AS A FUNCTION OF CAPACITORS

In setting the oscillator frequency adjustment, it is important that the control setting not be changed too rapidly. If the adjustment is turned quickly, the oscillator will stop oscillating, and the operator will have to wait several seconds for normal operation to be restored. Note that the amplitude adjustment affects only the amplitude of the signal provided at the rear-panel Ref. Osc. Out connector (impedance 600 ohms). The amplitude can be adjusted from 0 V to 10 V pk-pk. The amplitude of the signal supplied to the Model 129 Reference channel does not change. Neither does that supplied to the Ref. In connector, which acts as a monitor point when the unit is operated in conjunction with the internal oscillator. The monitor signal is a constant 1 V rms and its source resistance is 10 kΩ. The operator is not advised to use this monitor signal as the reference drive for his experiment.

The only other operating consideration is that of transferring the Model 129 from external reference operation to internal reference operation or vice versa. Internal wires fitted with quick-disconnect contacts determine wheth-

er the Reference channel is driven by the internal oscillator accessory or by an externally derived reference signal applied to the front panel jack. To gain access to these wires, it is necessary to first remove the instrument's cover, which is secured by four screws. When the cover is removed, locate the three adjacent board contacts, J418, J419, and J420. For operation in the Internal reference mode, the pink wire from the front-panel Ref. In connector is connected to J418. The white/orange wire from the Internal Oscillator is connected to J419. J420 is not used. For operation in the external mode, the pink wire from the front-panel connector is connected to J419. The white/orange wire is connected to J420, and J418 is not used. Also, the two frequency determining capacitors should be removed when operating with an external reference source.

4.7C INSTALLATION

When a Model 129 is ordered with the Internal Oscillator modification, the instrument is shipped with the oscillator installed and the operator need only concern himself with operating considerations. Should he desire to operate without the oscillator, he has only to transfer a few wires as described in the preceding paragraph.

If the Internal Oscillator is ordered separately, the installation is generally made by the customer. Three items are supplied, the oscillator board itself, a BNC connector with two wires attached, and a metal 'tag' bearing the word 'MONITOR'. The oscillator circuit board is secured to the Model 129 by standoffs which plug into openings in the Model 129 Reference board as shown in Figure IV-13. This figure also shows the location of the various interconnecting wires, all of which are terminated in quick-disconnect contacts so that the installation can be completed in a matter of minutes with no special tools or soldering required. The oscillator adjustments are ordinarily preset at the factory for 100 mV rms out at the frequency specified by the customer. The appropriate frequency range capacitors are factory inserted. The following procedure can be used to make the installation.

(1) Remove the top and bottom covers of the Model 129. The top cover is secured by four screws, two on each side. The bottom cover is secured by ten screws.

(2) Mount the BNC connector in the REF. OSC. OUT opening in the rear panel (it will be first necessary to push out the plug, which can then be discarded). Be sure to use the insulating bushings supplied so that there is no contact between the shell of the connector and chassis ground. After the connector is securely mounted, twist the two wires together, moderately tight, over their entire length.

(3) Note the pink wire which extends from the Ref. In connector to J419 near the front of the Ref. Bd. Remove this wire from J419 and allow it to hang free.

(4) Remove the Reference INPUT connector from the front panel. Then locate the 'Monitor' tag over the panel opening and remount the connector so that the tag is secured in place by the connector mounting flange.

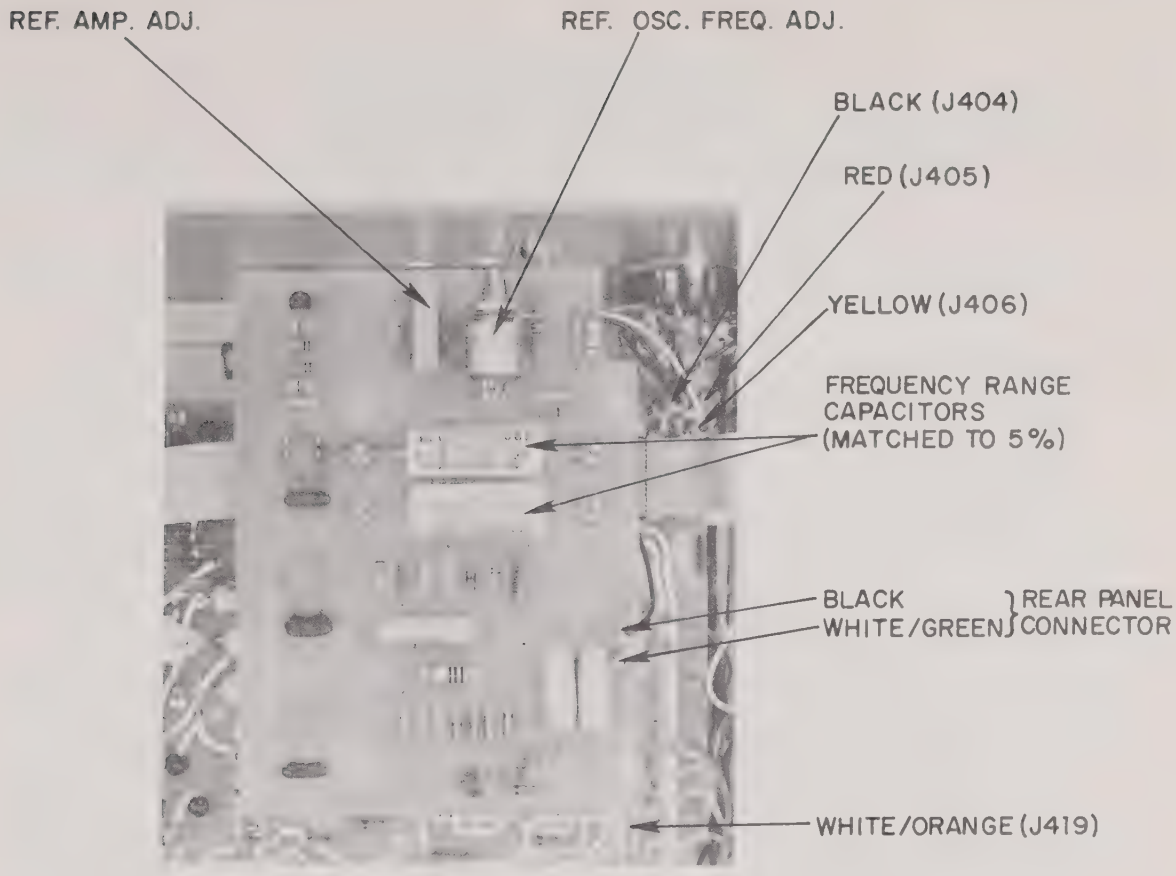


Figure IV-13. INTERNAL OSCILLATOR BOARD INSTALLED

(5) Position the oscillator board as shown in Figure IV-13 but do not snap it into place yet. Dress the red, yellow, and black wires out to the right, and the longer white/orange wire towards the front of the instrument.

(6) Connect the red, yellow, and black wires as follows.

red ---------- J405
yellow ---------- J406
black ---------- J404

(7) Connect the pink wire from the Ref. In connector to J418.

(8) Locate the white/orange wire from the oscillator and connect it to J419. Dress this wire along the Ref. Bd.

(9) Press the Oscillator board down until it snaps into place.

(10) Connect the black and white/green twisted leads (from the rear-panel connector) to the Oscillator board quick-disconnect contacts as shown in Figure IV-13.

This completes the installation. The top and bottom covers may now be reinstalled. To check the oscillator, simply turn on the power and monitor the oscillator output with an oscilloscope.

4.8 OPERATION WITH THE INTERNAL TUNED AMPLIFIER

4.8A INTRODUCTION

In some applications it is desirable to narrow the noise bandwidth ahead of the mixer, or to notch out a particular frequency component of the input signal. These operations are made possible if the Model 128 is operated in conjunction with the Model 129/98 Accessory Tuned Amplifier. With this accessory installed, bandpass or notch operation at a Q of 5 is possible over the entire frequency range of the Model 129.

Note from Figure IV-14, a photograph of the Model 129 with the Tuned Amplifier installed, that there are two trim-adjustments and two switches on the Tuned Amplifier circuit board. In addition, there are the two capacitors, mounted on special spring-loaded terminals, which determine the range of the frequency adjustment. The trim-adjustment accessible through an opening in the rear panel sets the center frequency of the Tuned Amplifier. That which is accessible from the side of the Model 129 sets the Q and amplitude response. These two adjustments interact to some degree. The two switches determine the tuned amplifier function. One of them allows the operator to select either Tuned Amplifier operation or Flat operation. The other gives the choice of Bandpass or Notch operation. These latter two functions have relevance only when the first switch is set to SELECTIVE. If it is set to FLAT, the tuned amplifier circuitry is bypassed and the Model 129 operates exactly as if the Tuned Amplifier had never been installed.

The frequency range of the rear-panel adjustment as a function of the value of the two replaceable capacitors is the same as for the Internal Reference Oscillator (Table IV-2). Also, the restrictions as to the types of capacitors which can be used are the same as outlined in Subsection 4.7B. There is, however, one difference, namely that the capacitors used in the Tuned Amplifier must be matched to 1%, whereas in the case of the Oscillator, they need only be matched to 5%. Capacitors purchased from PAR for use in the Tuned Amplifier are matched to 1%, even though they may be marked 5%. (This comes about because they are selected from a large stock of 5% capacitors.) Such 1% capacitors are marked by colored tape to prevent them from being confused with any other capacitors with which they might be stored.

4.8B OPERATION

The first step is to set the Tuned Amplifier to the intended operating frequency. An appropriate procedure follows. NOTE: Each Tuned Amplifier is preset at the factory to the frequency specified by the customer.

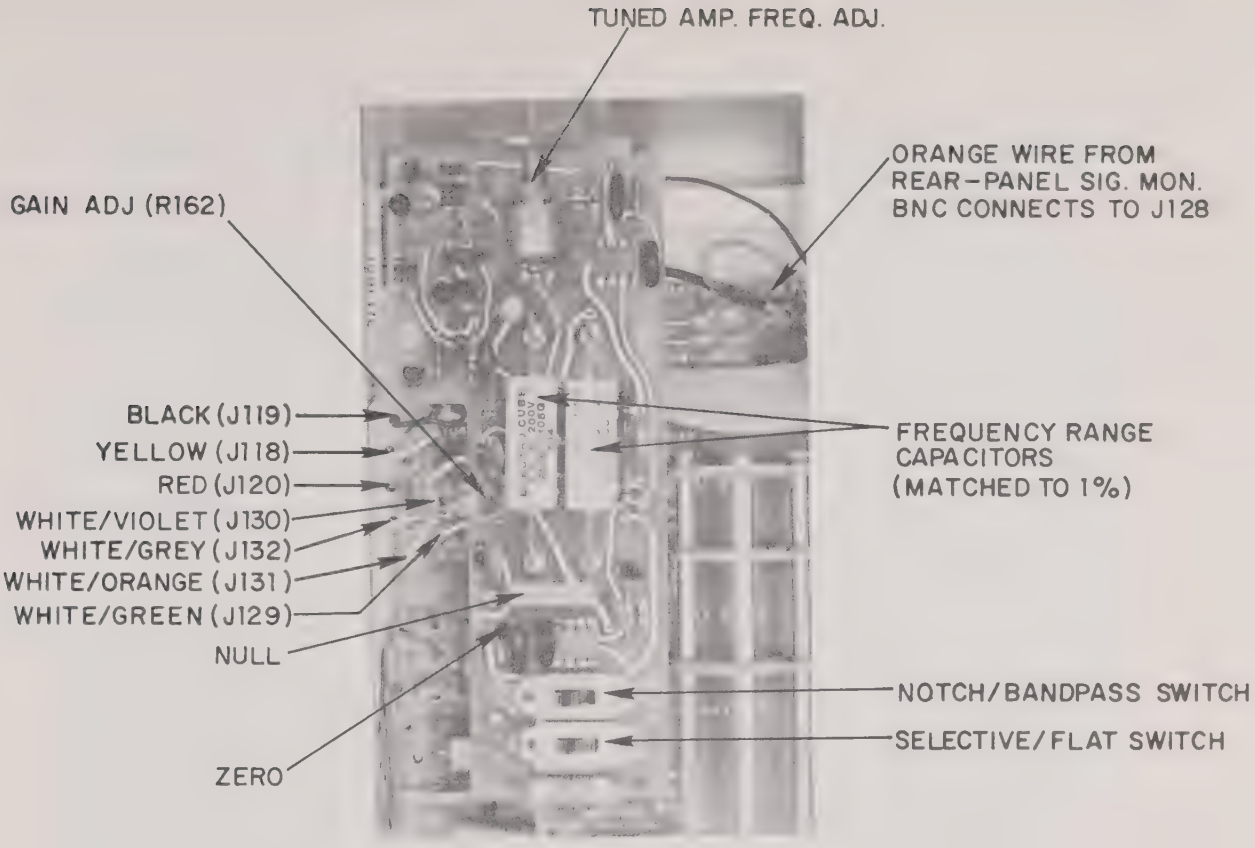


Figure IV-14. TUNED AMPLIFIER INSTALLED

(1) Remove the top cover of the Model 129. This cover is secured by four screws, two on each side.

(2) Set the Model 129 controls as follows.

Sensitivity	250 mV
Input	A
Low Pass	MAX
Hi Pass	MIN
Reference Mode	f
Vector switch	2 PHASE
Phase	
switch	270°
dial	90.0°
Time Constant (both)	.3 SEC.
Zero Suppress (both)	OFF (dial setting irrelevant)
Output Filter (both)	OUT
Output Expand (both)	X1

(3) Select and install the two capacitors which set the frequency range.

Be sure to use capacitors matched to 1%. NOTE: One set of capacitors, having the value appropriate to the frequency specified by the customer, is supplied with each Tuned Amplifier.

(4) Turn on the Model 129 power.

(5) Set the Flat/Selective slide switch on the Tuned Amplifier to SELECTIVE.

(6) Set the Notch/Bandpass slide switch to NOTCH.

(7) Connect a 250 mV rms sinewave (0.7 V pk-pk) to both the 'A' Input and Ref. Input of the Model 129. This signal should be at the intended operating frequency. NOTE: If the unit is also equipped with the internal oscillator modification, use the internal oscillator as the signal source.

(8) Monitor the rear-panel SIG. MON. connector with the oscilloscope and alternately adjust the two Tuned Amplifier trim-adjustments for a null in the observed signal. The rear-panel accessible adjustment sets the center frequency. The one which is adjusted from the side sets the Q and amplitude response. These adjustments do interact so it will be necessary to go back and forth until no further improvement in the observed null can be obtained. NOTE: Any time the operating frequency is changed, the Null/Amplitude adjustment must also be reset. If the Null/Amplitude adjustment is properly set for one end of the frequency range, and the tuned frequency is then shifted to the opposite end of the same range, the amplitude response of the Tuned Amplifier will be in error by about 20% unless the Null/Amplitude adjustment is reset.

(9) Set the Notch/Bandpass switch to BANDPASS. Then, using an accurate ac voltmeter, establish the rms amplitude of the <u>input</u> signal at 250 mV ±1%.

(10) Adjust the Phase dial (and Phase switch if need be) for peak In Phase panel meter indication (alternatively, one could use a DVM (digital voltmeter) connected to the In Phase OUT connector).

(11) Adjust the Model 129 GAIN CAL. trim-potentiometer, R162, for exactly full-scale panel meter indication (+1.000 V on a DVM). R162 is mounted on the Model 129 Signal Amplifier board directly beneath the Tuned Amplifier. It is accessible through an opening, labeled GAIN CAL, in the Tuned Amplifier circuit board.

The Model 129 is now tuned for bandpass operation at the intended operating frequency, and its gain is normalized for operation with the tuned amplifier. Figure IV-15 shows the phase/amplitude response of the Selective Amplifier in both Notch and Bandpass operation. For bandpass operation, the Notch/Bandpass switch should be set to BANDPASS. For Notch operation, it should be set to NOTCH. Neither position of the Notch/Bandpass switch has any relevance unless the Selective/Flat switch is set to SELECTIVE.

Note that this procedure must be modified somewhat for notch operation, where the frequency component to be removed is other than the one to be measured. As a result, the signal frequency used for setting up the Tuned Amplifier should be the one to be notched out, and not the one to be measured.

As can be seen from Figure IV-15, the Notch response is a sharp function of frequency. Hence, any slight frequency difference between the 'setup' signal and the 'real' signal to be notched out may result in the notch not being as deep as it could be. Hence, when the setup for notch operation is completed, it is generally a good idea to connect the signal produced by the experiment to the input of the Model 129 and then, while monitoring the signal at the SIG. MON. connector, to adjust the Null/Amplitude adjustment on the Tuned Amplifier as required to make the signal being nulled disappear into the noise. It might be mentioned that the 'appearance' of the transferred signal may not be as expected. For example, in measuring harmonics, it is generally desira-

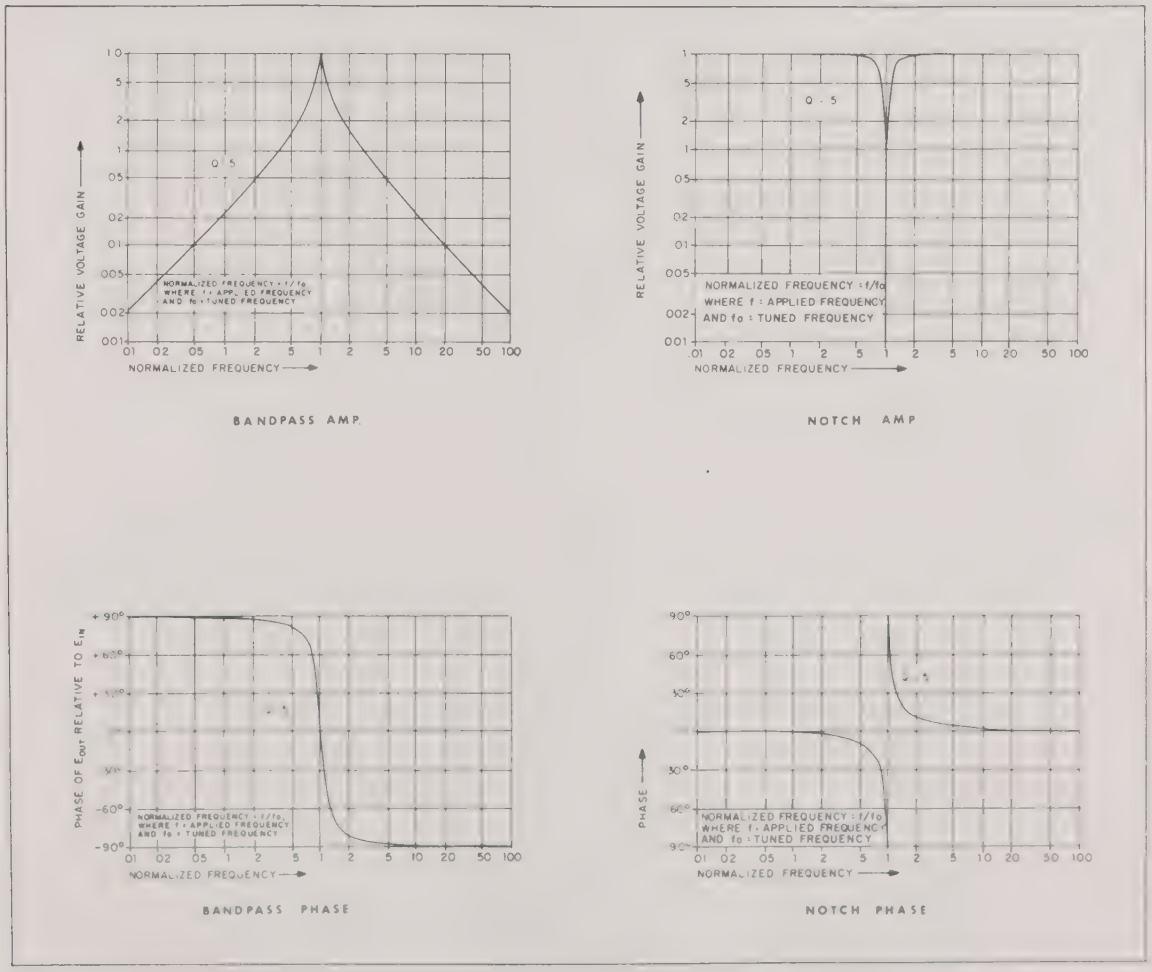


Figure IV-15. PHASE/AMPLITUDE CHARACTERISTICS OF TUNED AMPLIFIER

able to notch out the fundamental. Many observers are quite surprised by the appearance of a square wave, for example, which has had its fundamental frequency component removed.

4.8C INSTALLATION

When a Model 129 is ordered with the Tuned Amplifier modification, the instrument is shipped with the amplifier already installed and the operator need only concern himself with operating considerations. If he should wish to operate without the Tuned Amplifier, there are no changes to make other than to set the Selective/Flat switch to FLAT, although it may be desirable to touch up the setting of R162 using a test signal of accurately known amplitude.

In the case of a Tuned Amplifier which is ordered separately, the installation is generally made by the customer. Two items are supplied, the first being the Tuned Amplifier itself, and the second a BNC connector with an attached wire which terminates in a quick-disconnect contact. All of the interconnections between the Tuned Amplifier and the Model 129 are by means of wires attached to the Tuned Amplifier. These wires also terminate in quick-disconnect contacts. The following procedure can be used to make the installation.

(1) Remove the top cover from the Model 129. This cover is secured by four screws, two on each side.

(2) Mount the BNC connector in the SIG. MON. opening in the rear panel. (It will be first necessary to push out the plug, which can then be discarded.) Then connect the orange wire (attached to the connector) to pin J128 (rear edge of Signal Amp. Bd.).

(3) Position the Tuned Amplifier as shown in Figure IV-14 but do not snap it into place yet. (It is easier to make the wire connections first.)

(4) On the Model 129, remove the jumper (white/orange) which interconnects J129 and J130. Also remove the jumper (white/violet) which interconnects J131 and J132. It may be a good idea to tape these jumpers somewhere to a chassis surface inside the Model 129 to prevent their becoming lost.

(5) Make the wire connections from the Selective Amplifier to the following listed pins.

Wire Color	Connect To
black	J119
red	J120
yellow	J118
white/violet	J130
white/green	J129
white/orange	J131
white/gray	J132

(6) Press the Tuned Amplifier circuit board down so that it snaps into place.

This completes the installation. The Tuned Amplifier can now be operated as described in Subsection 4.8B.

SECTION V
ALIGNMENT

5.1 INTRODUCTION

The Model 129 Two-Phase/Vector Lock-In Amplifier is a reliable conservatively designed instrument. High quality stable components have been used throughout in its construction and one can reasonably expect a long period of troublefree operation without any need for realignment. However, to be assured of continued high confidence in the experimental data obtained with the Model 129, it may be advisable to run through the following alignment at one year intervals. Also, should it ever prove necessary to repair the instrument, it is advisable to do an alignment after the repair is completed but before the instrument is placed back in service.

Due to possible interactions between some of the adjustments, it is necessary that they be carried out in the indicated sequence. Any decision to make a partial alignment should be reserved to someone having sufficient knowledge of the Model 129 to fully understand all possible interactions. Figure V-1 identifies the adjustments and test points.

Note that this alignment is not intended to be used in troubleshooting. If the instrument is suspected of malfunctioning, go directly to Section VI, which deals with troubleshooting. The instrument must be working properly before it can be aligned.

5.2 REQUIRED EQUIPMENT

(1) General purpose oscilloscope having a sensitivity of at least 1 mV/cm with a 10:1 attenuator probe.

(2) General purpose sinewave oscillator (400 Hz and 100 kHz).

(3) Digital Voltmeter such as the Fairchild Model 7000A.

(4) Accurate ac voltmeter such as the HP Model 400 EL.

5.3 PRELIMINARY STEPS

(1) Remove the top cover, which is secured by four screws, two on each side. Once the screws are removed, slide the cover back far enough to free it, and then lift it off.

(2) If the unit is equipped with either the tuned amplifier or the internal oscillator, take the necessary steps to render these accessories inactive, that is, the Model 129 should be operated in the External Reference mode and the signal channel response should be flat. If unfamiliar with these accessories, refer to Subsections 4.7 and 4.8.

(3) Check and, if necessary, adjust the mechanical zero of each of the panel meters.

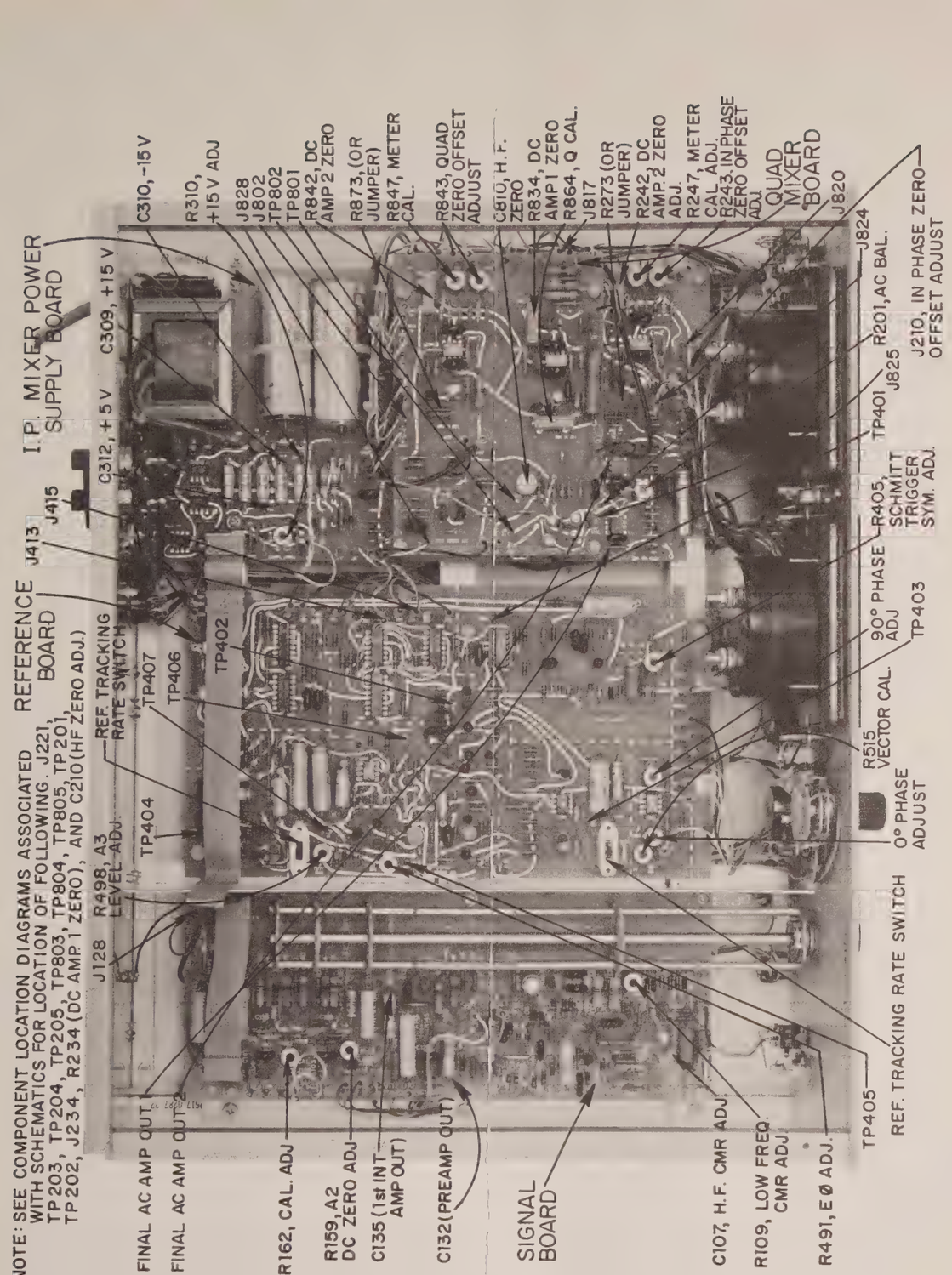


Figure V-1. ADJUSTMENTS AND TEST POINTS

(4) Connect the BNC shorting plugs (Amphenol CW-159/U or equivalent) to both signal inputs. Then plug in the line cord, turn on the power, and allow a fifteen minute warmup.

5.4 PROCEDURE

5.4A +15 V ADJUST (R310), -15 V CHECK, and +5 V CHECK

(1) Connect the DVM to the positive end of capacitor C309. Then adjust R310 (+15 V ADJ) for a DVM indication of +15.00 V.

(2) Remove the DVM from C309 and transfer it to the negative end of C310. The voltage there should be -15 V ±0.2 V.

(3) Remove the DVM from C310 and transfer it to the positive end of C312. The voltage should be +5 V ±0.2 V. Remove the DVM.

5.4B REFERENCE BOARD ADJUSTMENTS

(1) Set the Model 129 controls as follows.

Sensitivity	100 mV
Input Selector switch	'A'
Lo Pass switch	MAX.
Hi Pass switch	MIN.
Phase switch	0°
Phase dial	0°
Vector switch	2 PHASE
Reference Mode switch	f
I Time Constant	.3 SEC.
I Zero Offset	
switch	OFF
dial	0.00 (fully counterclockwise)
I Output Expand	X1
I Output Filter	1 SEC.
Q Time Constant	.3 SEC.
Q Zero Offset	
switch	OFF
dial	0.00 (fully counterclockwise)
Q Output Expand	X1
Q Output Filter	1 SEC.
Fast/Slow switches (located on Reference Board)	FAST

(2) Schmitt Trigger Symmetry Adjust (R405)

(a) Connect the oscillator to the Reference In connector. Set the amplitude to 3 V pk-pk and the frequency to 400 Hz.

(b) Monitor the signal at TP401 with the oscilloscope. The observed signal should be a 400 Hz square wave with a pk-pk amplitude of about 3 V.

(c) Gradually reduce the amplitude of the applied signal until 'rounding' of the square wave is observed. As the amplitude is further reduced, the symmetry of the observed waveform may become degraded. Adjust R405 (Schmitt Trigger Symmetry Adj) as required to maintain ideal symmetry. Keep reducing the amplitude and re-adjusting R405 until best symmetry is obtained with the lowest possible reference input which gives proper operation.

(d) Increase the amplitude of the reference input to 3 V pk-pk.

(3) A3 Level Adjust (R498)

(a) Trigger the oscilloscope externally, using the Reference Input signal.

(b) Taking care to use the 10:1 probe, dc couple the oscilloscope and connect it to TP407.

(c) Adjust R498 (A3 Level Adj) for -4 V at TP407. Then wait a minute and see if the voltage changes. If it does, readjust R498 for the desired -4 V reading.

(4) EØ Adjust (R491)

(a) AC couple the oscilloscope and transfer it from TP407 to TP405. The suggested horizontal sensitivity is 1 ms/cm.

(b) Rotate R491 (EØ Adjust) fully counterclockwise.

(c) Increase the vertical sensitivity of the oscillocope until small spikes are observed. Adjust R491 (EØ Adjust) and note that this control determines the width and polarity of the spikes. Ideally, the control is set as required to make the spikes disappear. However, short term thermal fluctuations resulting from air currents will generally make it impossible to get rid of the spikes altogether. The control is properly set when the spikes alternately change polarity from the ambient air currents.

5.4C SIGNAL BOARD ADJUSTMENTS

(1) A2 DC Zero Adjust (R159)

(a) Connect the DVM to J128.

(b) Adjust R159 (A2 DC Zero Adj) for 0 V ±50 mV. Remove the DVM.

(2) Cal. Adj. (R162)

(a) Remove the shorting plug from the 'A' Input. Then connect the signal generator output (400 Hz, 1 V pk-pk) to the 'A' Input. It is not necessary that the signal generator be connected to the Reference Input for this adjustment.

(b) Connect the oscilloscope (still externally triggered from the signal generator) to J128. The observed signal should be a sine-wave with an amplitude of 10 V pk-pk.

(c) Remove the shorting plug from the 'B' Input. Then set the Input Selector to '-B' and transfer the signal generator output (still 1 V pk-pk at 400 Hz) to the 'B' Input.

(d) The signal at J128 should be a sinewave with an amplitude of 10 V pk-pk. If the amplitude is not correct, adjust R162 (Cal. Adj) for the required 10 V pk-pk amplitude.

(e) Remove the oscilloscope and disconnect the signal generator from the 'B' Input. Reconnect the shorting plugs to both signal inputs. If the signal generator was removed from the Reference Input at the beginning of the preceding adjustment, reconnect it now.

5.4D IN-PHASE MIXER ADJUSTMENTS

(1) DC Amp. 2 Zero Adjust (R242)

(a) Connect a jumper from J221 to J820. Then connect another jumper between J820 and TP203, and yet another between TP204 and TP205. NOTE: Test points TP203, TP204, and TP205 are not provided in early units. If these test points are missing on the unit in question, substitute as follows. For TP203 use J210. For the jumper between TP204 and TP205, connect one across resistor R273. If the unit in question has a jumper installed in place of R273, there is not need to connect this jumper. The other two, however, should be connected as indicated.

(b) Adjust R242 (DC Amp. 2 Zero Adj) for '0' on the In Phase panel meter. NOTE: This is a sensitive high-gain adjustment and setting a true zero will generally prove impossible. Initially, the meter will probably be 'against the stops' in one direction or the other. As the adjustment is turned, a point will be reached where the meter indication 'snaps' to the other extreme. If the adjustment is then turned in the opposite direction, about a half turn will typically be required to make the indication 'snap back'. The correct setting is midway through the 'dead zone'. In other words, one must adjust the pot until the indication 'snaps' to the other extreme, then stop and go back half way to the setting required to make the meter 'snap back'.

(c) Remove the jumper which connects J820 and TP203, and also the one which connects TP204 and TP205. Do not disturb the connection from J820 to J221. NOTE: If the absence of test points TP203, TP204, and TP205 necessitated using 'substitute points' as indicated in step (a), adapt this step as appropriate.

(d) Connect the DVM to the front-panel In-Phase OUT connector. The DVM should read 0 ±2 mV. If the reading is out of tolerance, it

is an indication that the value of select-by-test resistor R273 should be changed. If necessary, try different value resistors until the desired reading is obtained. The value selected should always be less than 1 MΩ.

(2) DC AMP 1 Zero Adjust (R234)

(a) Remove the jumper which interconnects J221 and J820.

(b) Set the In-Phase Output Expand switch to X100.

(c) Adjust R234 (DC Amp 1 Zero Adj) for 0 ±0.0002 V on the DVM.

(d) Set the In-Phase Output Expand switch back to X1.

(3) Meter Cal Adjust (R247)

(a) Set the In-Phase Zero Suppress Polarity switch to '-'.

(b) Adjust the Zero Suppress dial clockwise (about one full turn) for a DVM indication of +1.00 V.

(c) Adjust R247 (Meter Cal. Adj) so that the In-Phase panel meter reads exactly full-scale to the right.

(d) Set the Zero Offset Polarity switch back to the OFF position and remove the DVM.

(4) AC Bal. Adj (R201)

(a) Set the In-Phase Output Expand switch to X100. Then set the In Phase Time Constant switch to MIN. and the In Phase Output Filter switch to OUT.

(b) Connect the oscilloscope to the front-panel In Phase OUT connector.

(c) Decrease the signal generator frequency to 40 Hz. NOTE: The signal generator should be connected to the Reference Input of the Model 129.

(d) Adjust R201 (AC BAL Adj) for minimum square-wave signal observed at the oscilloscope. NOTE: This square wave will drift around because of short term temperature fluctuations caused by air currents on the components.

(e) Set the In Phase Time Constant switch to .3 SEC and the In Phase Output Filter switch to 1 SEC.

(5) HF Zero Adj (C210)

(a) Increase the signal generator frequency to 100 kHz.

(b) Adjust C210 (HF Zero Adj) for '0' on the In-Phase panel meter.

This adjustment is accessible through a hole in the Quadrature Mixer board. NOTE: Some early units do not have this hole. Where this is the case, the Quadrature Mixer can be tilted up. This requires removal of the wires connected to J824, J825, and J828, with jumpers of appropriate length being used to reestablish these connections with the board tilted.

(c) Reset the signal generator frequency to 400 Hz and reset the Model 129 In-Phase Output Expand switch to X1.

5.4E QUADRATURE MIXER ADJUSTMENTS

(1) DC Amp 2 Zero Adjust (R842)

(a) Connect three jumpers as follows. The first is connected from J802 to J820, the second is connected between TP804 and TP805, and the third is connected between TP803 and J820 (also connected to J802). NOTE: Test points TP803, 804, and 805 are not provided in early units. In an instrument not having these test points, the jumpers should be connected to the equivalent components. J801 is the equivalent to TP803. The other two test points have their 'equivalents' at the two ends of select-by-test resistor R873. That end of R873 which is closest to the row of quick disconnect pins can be considered as TP805. The other end of R873 can be considered as TP804.

(b) Adjust R842 (DC Amp 2 Zero Adj) for zero on the Quadrature panel meter. NOTE: This is a sensitive high-gain adjustment which should be set as described for R242 on page V-4 (step 16).

(c) Remove the jumper which interconnects TP804 with TP805 and that which connects TP803 with J820. Leave the jumper which interconnects J802 and J820.

(d) Connect the DVM to the front panel Quadrature OUT connector. The DVM should read 0 ±0.0005 V. If the reading is out of tolerance, it is an indication that the value of select-by-test resistors R873 should be changed. If necessary, try different valued resistors until the desired reading is obtained. The value selected should be less than 1 MΩ.

(2) DC Amp 1 Zero Adjust (R834)

(a) Remove the jumper which interconnects J802 and J820.

(b) Set the Quadrature Output Expand switch to X100.

(c) Adjust R834 (DC Amp 1 Zero Adj) for '0' on the DVM. The front-panel Quadrature meter should also indicate zero.

(d) Set the Output Expand back to X1.

(3) Meter Cal Adjust (R847)

(a) Set the Quadrature Zero Offset Polarity switch to '-'.

(b) Adjust the Quadrature Zero Suppress dial as required to obtain a DVM indication of +1.00 V.

(c) Adjust R847 (Meter Cal) so that the Quadrature panel meter indicates exactly full scale to the right.

(d) Reset the Quadrature Zero Suppress Polarity switch to OFF.

(4) HF Zero Adjust (C810)

(a) Set the Quadrature Output Expand switch to X100.

(b) Increase the signal generator frequency to 100 kHz.

(c) Adjust C810 (HF Zero Adj) for '0' on the Quadrature panel meter.

(d) Reset the signal generator frequency to 400 Hz.

5.4F OTHER CHECKS

(1) Vector Calibrate (R515)

(a) Remove the shorting plug from the 'A' Input. Set the Input Selector to 'A' and connect the output of the signal generator to the A Input. The amplitude of the signal generator output should be set to 100 mV rms ±2%. The Reference Input of the Model 129 should be driven from 1 V rms. The operator can either use the same output of the signal generator in conjunction with a 10:1 divider to obtain the two signal levels, or use a generator which has two outputs. If the two signals are in phase, the following steps apply directly. However, if the two signals are in quadrature, such as could be the case if certain dual-output signal generators are used, the additional phase shift will have to be taken into account in setting the Model 129 front-panel Phase controls. To obtain the required amplitude accuracy, it may be advisable to set the signal channel input level with a calibrated ac voltmeter.

(b) Set the controls as follows.

'Q' Time Constant switch -------- 10 SEC.
'Q' Output Filter switch -------- OUT
'Q' Output Expand switch -------- X100
Vector switch ------------------ VECTOR

NOTE: These control settings transfer the instrument to vector/voltmeter operation, in which the 'I' Channel indicates amplitude and the 'Q' Channel phase. The Sensitivity switch should still be set to 100 mV, as directed in an earlier step.

(c) On the Reference Board, set R515 (Vector Calibrate) and R438 (0° Adj) to their fully clockwise positions.

(d) Adjust the front-panel Phase dial for '0' on the DVM (should still be monitoring the 'Q' Output, which reads phase in vector/voltmeter operation).

(e) Set the front-panel Phase switch to 90°.

(f) Adjust R515 (Vector Cal) for a DVM indication of 0.900 V ±1 mV.

(g) Reset the Phase switch to 0°. The DVM should indicate 0.000 V. If it does not, repeat steps d, e, and f. Then check '0' again. Repeat this sequence until no further improvement in either the 0 V or .9 V readings can be obtained.

(h) Reset the Vector switch to 2 PHASE, the Q Time Constant switch to .3 SEC., and the Q Output Expand switch to X1.

(2) Reference 0° Phase Adj (R438)

(a) Note the 'I' panel meter indication. It should be about full-scale to the right. NOTE: Again the operator is advised that these phase controlled indications apply only if the Signal and Reference inputs to the Model 129 are in phase.

(b) Set the Phase switch to 90° and the front-panel Phase dial to 0.00°. The 'I' panel meter indication should drop to 'near zero'. Then set the In Phase Output Expand switch to X10.

(c) Adjust R438 (0° Adj) for exactly '0' on the 'I' panel meter.

(3) Reference 90° Phase Adj (R437)

(a) Set the Phase switch to 0°.

(b) Set the Phase dial to 90.0° (nine turns clockwise). The 'I' panel meter should indicate 'near zero'.

(c) Adjust R437 (90° Adj) for '0' on the 'I' panel meter. Then set the In Phase Output Expand switch to X1.

(4) Cal. Adj (R162)

(a) Connect the DVM to the 'I' OUT connector. Then set the Phase switch to 270°.

(b) Monitor the signal being applied to the 'A' Input with an ac voltmeter known (through recent calibration) to be accurate to 2% at 400 Hz. Adjust the amplitude of the input signal so that it is exactly 100 mV rms.

(c) Set the 'Q' Output Expand to X10.

(d) Adjust the front-panel Phase dial as required for '0' on the 'Q' panel meter.

(e) Adjust R162 (Cal. Adj) for 1.000 V on the DVM.

(5) Q Cal. Adjust (R864)

(a) Set the 'Q' Output Expand switch to X1.

(b) Set the front-panel Phase switch to 180°.

(c) Connect the DVM to the 'Q' OUT connector.

(d) Adjust R864 (Q Cal. Adj) for 1.000 V ±0.001 V on the DVM.

(6) In Phase Zero Offset Adjust (R243)

(a) Set the front-panel Phase switch to 270°.

(b) Connect the DVM to the 'I' OUT connector.

(c) Set the 'I' Zero Offset dial to 10.00 (fully clockwise) and the accompanying polarity switch to '+'. Then set the 'I' Output Expand switch to X10.

(d) Adjust R243 ('I' Zero Offset Adj) for 0.000 V at the DVM.

(e) Set the 'I' Output Expand switch back to X1 and the 'I' Zero Offset toggle switch to OFF. The DVM should indicate 1.00 V ±5 mV. If it does, go on to the following step. If it does not, it will be necessary to repeat steps 4, 5, and 6 as required to obtain the proper readings for adjusting R162 (step 4), R864 (step 5), and R243 (step 6).

(7) Quadrature Zero Offset Adjust (R843)

(a) Set the front-panel Phase switch to 180°.

(b) Connect the DVM to the 'Q' OUT connector.

(c) Set the 'Q' Offset Polarity switch to '+' and the accompanying Offset dial to 10.00 (fully clockwise).

(d) Set the 'Q' Output Expand switch to X10.

(e) Adjust R843 (Zero Offset Adj) for a DVM indication of 0 V ±5 mV.

(f) Set the 'Q' Zero Offset Polarity switch to OFF and the 'Q' Output Expand switch to X1. The DVM should indicate 1 V ±5 mV. If it does, go on to the following step. If it does not, it is because of interaction between R864 (Q Cal. Adj, step 5) and R843 (Quad. Zero Offset Adj, step 7). Repeat steps 5 and 7 until the desired adjustment objectives are achieved. Do not repeat step 6.

(8) Low Frequency CMR Adj (R109)

(a) Set the 'I' and 'Q' Zero Suppress dials fully counterclockwise.

(b) Set the front-panel Phase switch to 270°.

(c) Remove the shorting plug from the 'B' Input. Then connect the input signal simultaneously to both the 'A' and 'B' Inputs and set the Input Selector switch to A-B.

(d) Increase the level of the input signal to 1 V rms (if using an attenuator to provide different level signal channel and reference channel input levels, remove the attenuator). Then reconnect the signal to the Reference Input.

(e) Set the Sensitivity switch to 100 μV. Then adjust R109 (Low Frequency CMR Adj) for '0' on the 'I' panel meter.

(f) Set the In-Phase Output Expand switch to X10. Then readjust R109 (Low Frequency CMR Adj) for '0' on the 'I' panel meter.

(g) Reset the In-Phase Output Expand switch to X1.

(9) High Frequency CMR Adj (C107)

(a) Set the Sensitivity to 250 mV.

(b) Increase the frequency of the applied signal to 100 kHz and set the amplitude of the applied signal to 250 mV rms.

(c) Connect the oscilloscope (with probe) to J128 (quick disconnect at the rear of the Signal board).

(d) Adjust trim-capacitor C107 for minimum observed signal. It should be possible to adjust the observed signal to less than 60 mV pk-pk.

(10) High Frequency Phase Adj (R521)

(a) Make provision for supplying in-phase signals to the Model 129. The signal to be applied to the Reference Input should have an amplitude of nominally 1 V rms, while that applied to the Signal Input should be 100 mV rms. It is absolutely essential that the two signals be in phase. This is assured by using a single source and a simple series 10:1 divider. A 900 ohm composition resistor in series with a 100 ohm composition resistor makes a suitable divider. A signal having a nominal one volt rms amplitude is applied to the divider and to the Reference Input of the lock-in amplifier, while the signal applied to the Signal Input connector is taken from the junction of the two resistors.

(b) Set the signal frequency to 100 kHz and adjust the signal source output amplitude so that the signal applied to the Model 129 'A' Input is 100 mV rms.

(c) Set the Input Coupling switch to 'A'.

(d) Set both the Phase switch and the Phase dial to 0°.

(e) Set the Quadrature Output Expand switch to X10.

(f) Adjust R521 (High Frequency Phase Adjust) for '0' on the Quadrature panel meter.

This completes the alignment. The test equipment can now all be removed and the cover secured in place.

SECTION VI
TROUBLESHOOTING

6.1 INTRODUCTION

This section consists of a series of procedures to be followed in troubleshooting the Model 129. By making voltages and waveform checks at critical points it should be possible to narrow the trouble down to one of the plug-in circuit boards. Once the faulty board has been identified, the operator is advised to contact the factory or the authorized representative in his area for advice on how to get the instrument back into operation in the shortest possible time. In the case of units still in Warranty (Section VII), it is particularly important that the factory or one of its representatives be contacted before doing any work on the board itself, as any damage incurred from unauthorized work could invalidate the Warranty.

Although past experience indicates that most instrument failures are caused by a specific component failure on one of the boards, it is of course perfectly possible that a component other than one located on a circuit board could go bad. Where this is the case, the person troubleshooting will have to appropriately adapt the procedure to isolate the faulty component.

6.2 BLOCK DIAGRAM DISCUSSION

As can be seen from Figure VI-1, a simplified block diagram of the Model 129, the instrument can be thought of as consisting of three sections or 'channels'. The first is the Signal Channel, which consists of a series of amplifiers and gain switching circuits, the second is the Reference Channel, which takes the Reference Input waveform and from it develops suitable drives for the two Mixers, and the third is the Output Channel, which consists of the Mixers along with the following dc amplifiers and filtering circuits. Each of these is considered in greater detail in the following paragraphs.

6.2A SIGNAL CHANNEL

The input signal is applied to either (or both in the case of differential operation) of the two Input connectors. The following Selector switch determines how these connectors are routed to the Low Noise Preamplifier, which has a fixed gain of ten. The Preamplifier is followed by additional 'intermediate' amplifiers which provide additional amplification. The Input filters and Gain switching circuits are associated with these amplifiers as well. Next are the two Final AC Amplifiers which directly drive the signal inputs of the Mixers. The overall gain of the Signal Channel, measured from the input to either of the Final AC Amplifier outputs, is simply 1/S, where 'S' is the actual Sensitivity switch setting. For example, with the Sensitivity switch set to 1 mV, the overall Signal Channel gain is $1/10^{-3} = 10^{3}$.

6.2B REFERENCE CHANNEL

Of the three channels, the Reference Channel is the most complex. Its purpose is to generate two orthogonal square wave signals at the same frequency as the input Reference signal and synchronous with it. The phase of these

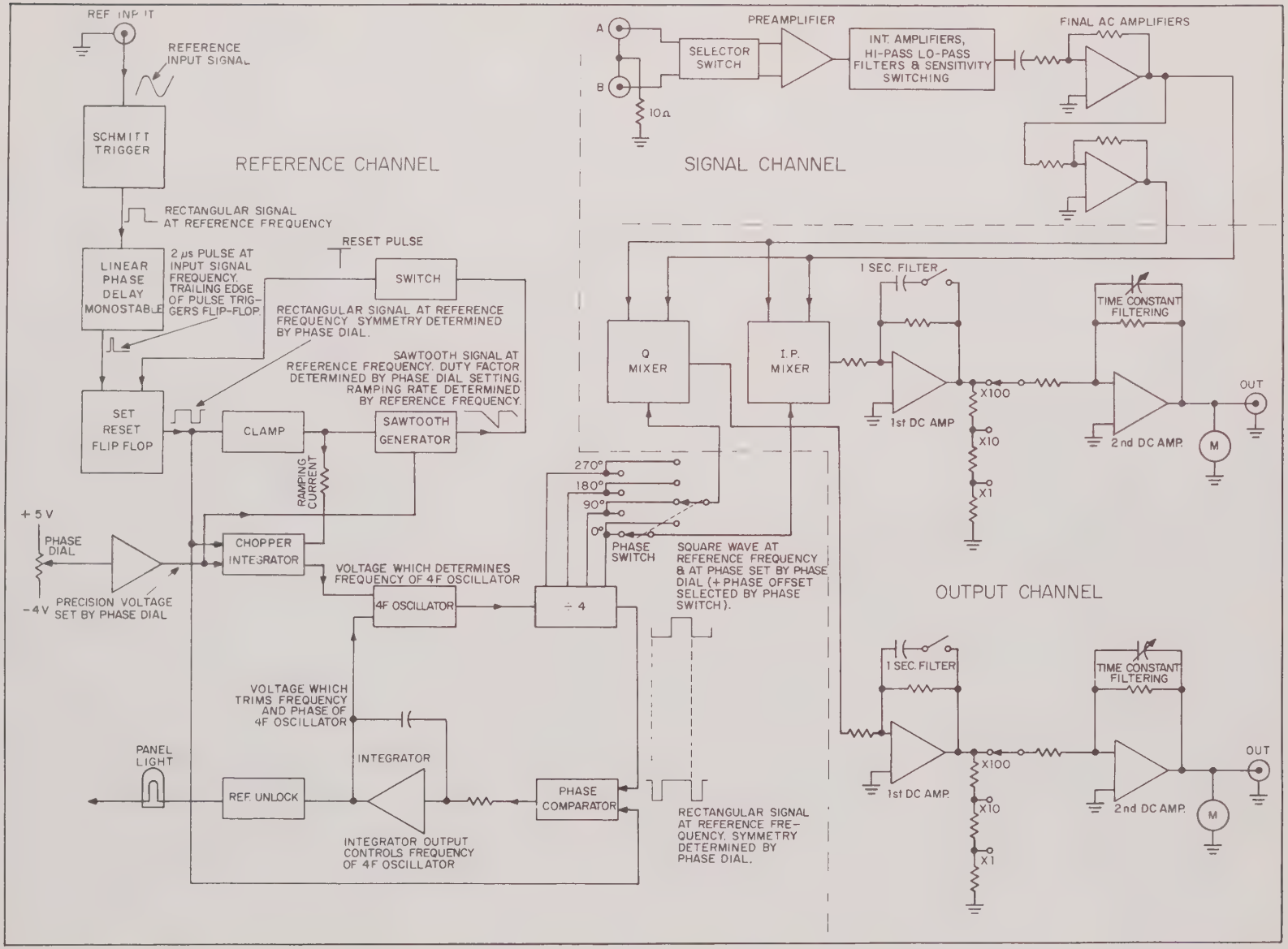


Figure VI-1. SIMPLIFIED BLOCK DIAGRAM

signals must be such that the phase of the signal applied to the In Phase Mixer, relative to the phase of the applied reference signal, leads by the angle set by the Model 129 Phase controls. The square wave applied to the Quadrature Mixer leads by an additional 90°. Additionally, the Reference Channel must track changes in the applied signal so as to maintain correct phase and frequency in the Reference Channel output signals at all times.

Referring to Figure VI-1, note that the first Reference Channel circuit is a Schmitt Trigger which 'sharpens' the applied reference signal. The output of the Schmitt Trigger, following a delay provided to compensate high frequency phase shift in the Signal Channel, is applied to a set-reset flip-flop. The output of this circuit is also a rectangular wave, but one having its symmetry controlled by the setting of the Phase dial. Each negative transition of the delayed Schmitt Trigger output sets the flip-flop, releasing the 'clamp' on the input of the following Sawtooth Generator to initiate a negative going ramp. When the ramp reaches some fixed voltage, a switch circuit resets the flip-flop. This action in turn clamps the Generator input, resetting the ramp and terminating the reset pulse from the switch. Thus, for each cycle of the reference input signal, there is one cycle of flip-flop output with the symmetry of this output in turn being governed by the duration of the sawtooth. Two factors determine the duration of a given sawtooth. The first is the initial ramp potential (the final or end-of-ramp potential is fixed) and the second is the ramping rate. Changing either of these factors can change the duration of a given ramp. Both, in fact, are controlled. Note that the Phase dial picks a voltage from a potentiometer and that this voltage, after being routed through a buffer amplifier and a FET switch, is applied to the Sawtooth Generator. At the generator, this voltage sets the initial potential of the ramp and thus the ramp duration. Because the ramp duration directly sets the symmetry of the flip-flop output, the Phase dial setting effectively sets the symmetry. However, this 'direct' control does not give the necessary accuracy to the Phase-Symmetry relationship. A servo loop is used to provide the 'fine control'. As shown in the block diagram, the phase-dial voltage is also applied to a Chopper-Integrator, where it is chopped by the flip-flop output and then integrated. Note also that the Chopper-Integrator determines the ramping current available to the Sawtooth Generator. Whenever the symmetry of the flip-flop output is such that the chopped and integrated voltage from the Phase dial differs from the value proper for the Phase dial setting, the ramping current, and hence the ramping rate and flip-flop symmetry, is corrected. Thus the flip-flop output symmetry tracks and corresponds to the Phase dial setting with a high degree of accuracy.

One characteristic that might not be immediately obvious is that the ramping rate varies with frequency as well. If the applied reference frequency should change, the symmetry would suddenly be 'wrong' for the dialed phase, with a resultant adjustment in the ramping current supplied to the Sawtooth Generator. High ramping currents are provided for fast ramps at high frequencies. Low ramping currents are provided for slow ramps at low frequencies.

Note that there are two outputs from the Chopper-Integrator. The first, as explained above, controls the ramping current supplied to the Sawtooth Generator. The second is a corresponding voltage which determines the oscillation

frequency of the 4F Oscillator. This oscillator, which oscillates at a frequency four times that of the applied reference signal, is followed by a pair of flip-flops that divide by four and provide a four-pole reference output. In the same manner as the 'direct' Phase dial voltage gives only a first order symmetry control by setting the initial potential of the ramp, the Chopper Integrator output only provides a first order control of the oscillator frequency. Another servo-loop does the fine frequency/phase tuning. One output of the divide-by-four circuit is applied to a Phase Comparator, which has as its other input the output of the set-reset flip-flop. Because the symmetry of the flip-flop accurately reflects the Phase dial setting, accurate phase information is provided for controlling the 4F Oscillator. If there is any difference between the phase of the divide-by-four circuit output and the phase information carried in the flip-flop output, the Phase Comparator develops an error output which acts through an Integrator to correct the frequency/phase of the 4F Oscillator. Thus the 0° Reference Channel output is servoed to exactly the phase selected with the front-panel Phase dial. The front-panel Phase switch allows additional phase 'offsets' of 90°, 180°, or 270° to be added for full four-quadrant coverage. Note that the signals supplied to the Mixers are 90° apart.

Operation with the front-panel Reference Mode switch set to '2f', although not shown on the block diagram, is essentially the same. The principal difference is that the 4F Oscillator runs at eight times the applied reference frequency instead of at four times the applied reference frequency. This is done by changing the Chopper Integrator operation so that it supplies twice the ramping current to the Sawtooth Generator and a higher voltage to the 4F Oscillator. Doubling both assures that the oscillator will run at twice its normal frequency and also that the symmetry of the flip-flop output carries correct phase information. Whereas in 'f' operation the full-scale range of the Phase dial is 0°-to-100° relative to the applied reference signal, in '2f' operation that range is reduced to 0°-to-50°. This restricted range corresponds to the desired 0°-to-100° in the 2f signal which drives the reference input to the Mixers.

6.2C OUTPUT CHANNEL

The Model 129 Mixers act as double-pole double-throw switches to provide full-wave synchronous rectification of the signal being processed. Figure IV-2 shows the switching arrangement used along with typical input and output waveforms. The phase relationships assumed are that the input signal is in phase with the reference input and that the Phase controls are set to 0°. The output of each Mixer is the average value of the rectified input. Under the assumed conditions, the In Phase Mixer output is maximum and the Quadrature Mixer output is zero. Note that the waveforms shown apply only with a noiseless input signal. If this signal were accompanied by noise and interference, they would appear at both the input and output of the Mixers. However, because of the synchronous rectification technique, noise and non-coherent interference would not contribute to the net dc applied to the dc amplifiers because noise and non-coherent interference have an average value of zero. The necessary averaging is provided by the filtering circuits associated with the dc amplifiers. Note that the one second filtering takes place in the first dc amplifier while the filtering determined by the Time Constant switch takes place at the second amplifier. The output expansion function is achieved by an attenuator interposed between the two amplifiers.

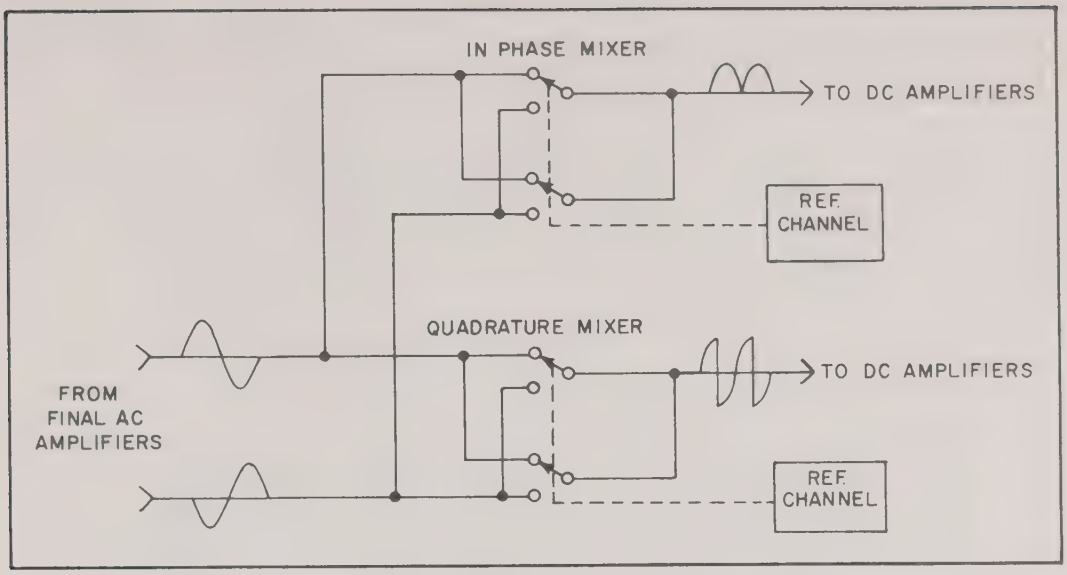


Figure VI-2. MECHANICAL SWITCH EQUIVALENT OF MIXER CIRCUITS

6.3 VECTOR VOLTMETER OPERATION

Although not illustrated in the block diagram, vector voltmeter operation is easily understood in that only minor switching is required to convert the instrument from lock-in amplifier operation to vector voltmeter operation. When the Vector switch is placed in the Vector position, the final Quadrature Channel dc amplifier is operated as a true integrator by removing the feedback resistor, with the selected Time Constant capacitor determining the integrating rate for a given input to the amplifier. At the same time, the output of this amplifier is routed back to the input of the buffer amplifier which is interposed between the phase dial and the circuits it controls, thus introducing a 'phase offset command'. The polarity around the loop is such (established by first operating for positive in-phase indication) that the offset drives the phase in the direction which reduces the output of the Quadrature Mixer, with equilibrium being at zero Quadrature Mixer output. Thus, at equilibrium, the reference input to the Quadrature Mixer is truly held in quadrature with the input signal and the reference input to the In-Phase Mixer is held at 0°. Thus the Magnitude can be read from the In Phase meter directly. The output from the final dc amplifier (integrator in vector voltmeter operation) required to maintain equilibrium gives the phase of the input signal relative to the applied reference.

6.4 EQUIPMENT NEEDED

(1) Digital Voltmeter such as the Fairchild Model 7000.

(2) Oscillator (sinewave) to provide a 100 mV rms signal at 400 Hz.

(3) General purpose oscilloscope with 10:1 probe.

6.5 INITIAL STEPS

(1) Remove the top cover, which slides off to the rear after removal of the four screws which secure it.

(2) If the unit contains a tuned amplifier or an internal oscillator, take the necessary steps to render these accessories inactive, that is, the Model 129 should be operated in the External Reference mode and the signal channel response should be flat.

(3) Plug in the Model 129, turn on the power, and allow a fifteen minute warmup.

6.6 POWER SUPPLY CHECKS (schematic on page VIII-8)

(1) On the Power Supply board, check for: (a) +15 V ±0.1 V at the positive end of capacitor C309, (b) -15 V ±0.2 V at the negative end of capacitor C310, and (c) +5 V ±0.2 V at the positive end of capacitor C312. If these voltages are correct, go to Subsection 6.7. If any of these voltages are incorrect or missing, proper power supply operation must be established before any further checks can be made. Note from the schematic on page VIII-8 that the +15 V regulator supplies the reference voltage for both the +5 V and -15 V regulators. Thus, any trouble with the +15 V regulator would cause loss of regulation in the -15 V and +5 V circuits as well.

(2) If the unregulated supply levels are incorrect (nominally ±24 V), check the unregulated supply components (line fuse, transformer, rectifiers, and filter capacitors). Note that the pass transistor for each of the three regulator circuits is bolted directly to the rear chassis, which acts as a heat sink.

6.7 REFERENCE CHECKS (schematics on pages VIII-4 and VIII-5)

(1) Set the controls as follows.

Input Selector	A
Sensitivity	100 mV
Phase	
switch	0°
dial	0°
Reference Mode	f
Vector switch	2 PHASE
Zero Offset switches	OFF
Zero Offset dials	fully counterclockwise
Output Expansion switches	X1
Output Filters	OUT
Time Constant switches	.3 SEC.
Reference Tracking-Rate switches	
(internal)	FAST
Power	ON (from previous checks)

(2) Set the oscillator controls to provide a 280 mV pk-pk (100 mV rms) sinewave at 400 Hz.

(3) Connect the output of the oscillator to the Reference Input of the Model 128.

(4) Connect the oscilloscope (use 10:1 probe) to TP401. The observed signal should be a 400 Hz square wave having its lower level at about -0.6 V and its upper level at +2.5 V. If this signal is as indicated, one can assume that the Input Schmitt Trigger circuit is working correctly. NOTE: Here and throughout the remainder of the trouble-shooting procedure the operator should concern himself primarily with gross discrepancies. Generally, when a circuit malfunctions, the 'error' in the output signal of that circuit is so great as to leave no doubt that the circuit is not working correctly. Much time may be saved by going through the checks fairly rapidly, without wasting undue time and effort trying to verify that each signal or voltage conforms to the value indicated down to the 'last decimal point'.

(5) Connect the oscilloscope to TP402. The observed signal should be a negative sawtooth at 400 Hz. The upper 'plateau' should be at +10 V and lower 'points' should be at +4.5 V. The 'plateau' intervals should have the same duration as the sawteeth. If this signal is as indicated, one can reasonably assume that the sawtooth generator circuit is working correctly.

(6) Connect the DVM to TP403. The voltage should be -4.5 V ±0.2 V. If this voltage is correct, one can conclude that all of the circuits shown in the page VIII-4 schematic are working normally.

(7) Connect the oscilloscope to TP404. The signal there should be a 1600 Hz square wave having its upper level at about +4 V and its lower at 0 V. If this signal is as indicated, one can reasonably assume that the 4F Oscillator, pair Q427-Q428, the Phase Comparator, and the Integrator are all working correctly.

It might be instructive to check the voltage at TP407. The allowable voltage range at this point extends from 0 V to -8 V. However, under the measurement conditions established, this voltage is nominally -4 V. The voltage at TP406 should be about -0.6 V relative to that at TP407.

The correction signal can be observed at TP405. However, when the loop is operating correctly, there is little to observe. One might see small spikes of either polarity at 400 Hz. Should the loop be perturbed by changing the frequency of the applied reference signal, these spikes transform into definite 200 mV rectangular pulses which can be either positive or negative according to the sense of the correction to be made.

(8) Monitor J413 with the oscilloscope. One should observe a 400 Hz square wave having its upper level at +4 V and its lower at 0 V. If this waveform is as indicated, one can conclude that the Reference drive to the In Phase Mixer is normal. Similarly, one can monitor the Quadrature Mixer drive signal at J415. By triggering the oscilloscope from one of these signals while monitoring the other, it should be easy to verify that they are in quadrature.

If all of these voltage waveform checks gave the indicated results, it is reasonable to assume that the entire Reference Channel is working correctly.

6.8 SIGNAL CHANNEL AMPLIFIERS

6.8A PREAMPLIFIER (schematic on page VIII-2)

(1) Connect the oscillator output (still set to 280 mV pk-pk at 400 Hz) to the 'A' Input of the Model 129. This signal should still be applied to the Reference Input as well.

(2) Connect the oscilloscope to the negative end of capacitor C132 (see Figure V-1). NOTE: This capacitor is shown schematically on page VIII-3. The observed signal should be a sinewave with a pk-pk amplitude of 2.8 V, indicating that the preamplifier has the expected gain of ten.

6.8B INTERMEDIATE AC AMPLIFIERS (schematic on page VIII-3)

(1) Connect the oscilloscope to quick-disconnect pin J128. The observed signal should be a 400 Hz sinewave with a pk-pk amplitude of 2.8 V. If this signal is as observed, one can go on to 6.8C. If the signal is not as indicated, the following checks can be made to determine in which of the three Intermediate Amplifiers the trouble is located.

(a) Monitor the signal at the negative end of capacitor C135 (see Figure V-1). The signal observed should be a sinewave with a pk-pk amplitude of 2.8 V. If this signal is as indicated, one can conclude that the first Intermediate Amplifier is also functioning normally.

(b) Connect the oscilloscope to quick-disconnect pin J131. The signal there should be a sinewave with a pk-pk amplitude of 2.8 V. If this signal is as indicated, the second Intermediate Amplifier is also functioning normally.

Since the output of the third Intermediate Amplifier has already been checked (quick-disconnect pin J128), and it is reasonable to assume that one would not be doing this check unless the signal at J128 was abnormal, then one may conclude, based on a normal reading at J131, that the problem is associated with the third Intermediate Amplifier.

6.8C FINAL AC AMPLIFIERS (schematic on page VIII-7)

Monitor the two Final AC Amplifier outputs at the points shown in Figure V-1. The signal observed at both points should be a 2.8 V pk-pk sinewave at 400 Hz. If this signal is as indicated, one may conclude that all of the Signal Channel ac amplifiers, including the two final buffers, are functioning normally.

6.9 IN PHASE MIXER (schematic on page VIII-7)

(1) Set the Phase switch to 270° and the Phase dial to 90°.

(2) Verify that the 280 mV pk-pk oscillator output is still being applied to both the Signal and Reference inputs of the Model 128.

(3) Connect the oscilloscope to TP201. The observed signal should be a full-wave rectified sinewave with a peak amplitude of 1.5 V. A slight adjustment of the Phase dial may be required to obtain this waveform. If this signal is as indicated, one may conclude that the Mixer circuit (Q201 through Q204) is functioning normally.

(4) If this signal is incorrect or missing, check the Mixer Reference drive signal, which can be monitored at TP202. One should observe a 400 Hz square wave having its upper level at +6 V and its lower level at -8 V. If this signal is as indicated, one may conclude that the Reference Amplifier Limiter, which directly supplies the reference signal to the Mixer circuit, is functioning normally.

6.10 QUADRATURE MIXER (schematic on pages VIII-9 and VIII-10)

(1) Set the Phase switch to 180°.

(2) Connect the oscilloscope to TP801. The observed signal should be a positive full-wave rectified sinewave with a peak amplitude of +1.5 V. If this signal is as indicated, one may conclude that the Quadrature Mixer (Q801 through Q804) is functioning normally.

If this signal is missing or incorrect, check the Quadrature Mixer Reference Drive signal, which can be monitored at TP802. One should observe a 400 Hz square wave having its upper level at +6 V and its lower level at -8 V. If this signal is as indicated, one may conclude that the Reference Amplifier Limiter, the circuit interposed between the output of the Reference Channel and the Quadrature Mixer, is functioning normally.

6.11 IN PHASE DC AMPLIFIERS

(1) Set the Phase switch to 270°. The In Phase panel meter should indicate full-scale. If necessary, make a minor adjustment in the setting of the Phase dial to be sure the phase is set for peak meter indication. If the indication is not exactly full scale, adjust the amplitude of the input signal for the desired full-scale indication.

(2) Connect the DVM to quick-disconnect pin J234. The voltage should be -5 V ±0.2 V. If this voltage is as indicated, the first dc amplifier is functioning normally.

(3) The output of the final amplifier can be measured at either the Recorder Output or at the front-panel Output connector. At either place the voltage should be +1 V ±50 mV (assuming the input signal is the specified amplitude). If readings other than those indicated are obtained, the trouble is associated with the final dc amplifier.

6.12 QUADRATURE DC AMPLIFIERS

(1) Set the Phase switch to 180°. Now the Quadrature meter should indicate full scale.

(2) Connect the DVM to quick-disconnect pin J817. The voltage should be -5 V ±0.2 V. If this voltage is as indicated, the first Quadrature dc amplifier is functioning normally.

(3) The output of the final Quadrature amplifier can be measured at either the Recorder Output or at the front-panel Quadrature Output connector. At either point the voltage should be +1 V ±50 mV. If readings other than these are noted, the problem lies with the final dc amplifier.

This completes the troubleshooting procedure. If no indication of trouble has been found to this point, the instrument is either functioning normally, or the problem is beyond the scope of this procedure. For additional aid or advice, the operator is advised to contact the factory or the authorized representative in his area.

SECTION VII
WARRANTY

Princeton Applied Research Corporation warrants each instrument of its own manufacture to be free from defects in material and workmanship. Obligations under this Warranty shall be limited to replacing, repairing or giving credit for the purchase price, at our option, of any instrument returned, shipment prepaid, to our factory for that purpose within ONE year of delivery to the original purchaser, provided prior authorization for such return has been given by an authorized representative of Princeton Applied Research Corporation.

This Warranty shall not apply to any instrument, which our inspection shall disclose to our satisfaction, to have become defective or unworkable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation, or other causes beyond our control. This Warranty likewise shall not apply to any instrument or component not manufactured by Princeton Applied Research Corporation. When products manufactured by others are included in Princeton Applied Research Corporation equipment, the original manufacturer's warranty is extended to Princeton Applied Research Corporation's customers.

Princeton Applied Research Corporation reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

THERE ARE NO WARRANTIES WHICH EXTEND BEYOND THE DESCRIPTION ON THE FACE HEREOF. THIS WARRANTY IS IN LIEU OF, AND EXCLUDES ANY AND ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESSED, IMPLIED OR STATUTORY, INCLUDING MERCHANTABILITY AND FITNESS, AS WELL AS ANY AND ALL OTHER OBLIGATIONS OR LIABILITIES OF PRINCETON APPLIED RESEARCH CORPORATION, INCLUDING, BUT NOT LIMITED TO, SPECIAL OR CONSEQUENTIAL DAMAGES. NO PERSON, FIRM OR CORPORATION IS AUTHORIZED TO ASSUME FOR PRINCETON APPLIED RESEARCH CORPORATION ANY ADDITIONAL OBLIGATION OR LIABILITY NOT EXPRESSLY PROVIDED FOR HEREIN EXCEPT IN WRITING DULY EXECUTED BY AN OFFICER OF PRINCETON APPLIED RESEARCH CORPORATION.

SECTION VIII
SCHEMATICS

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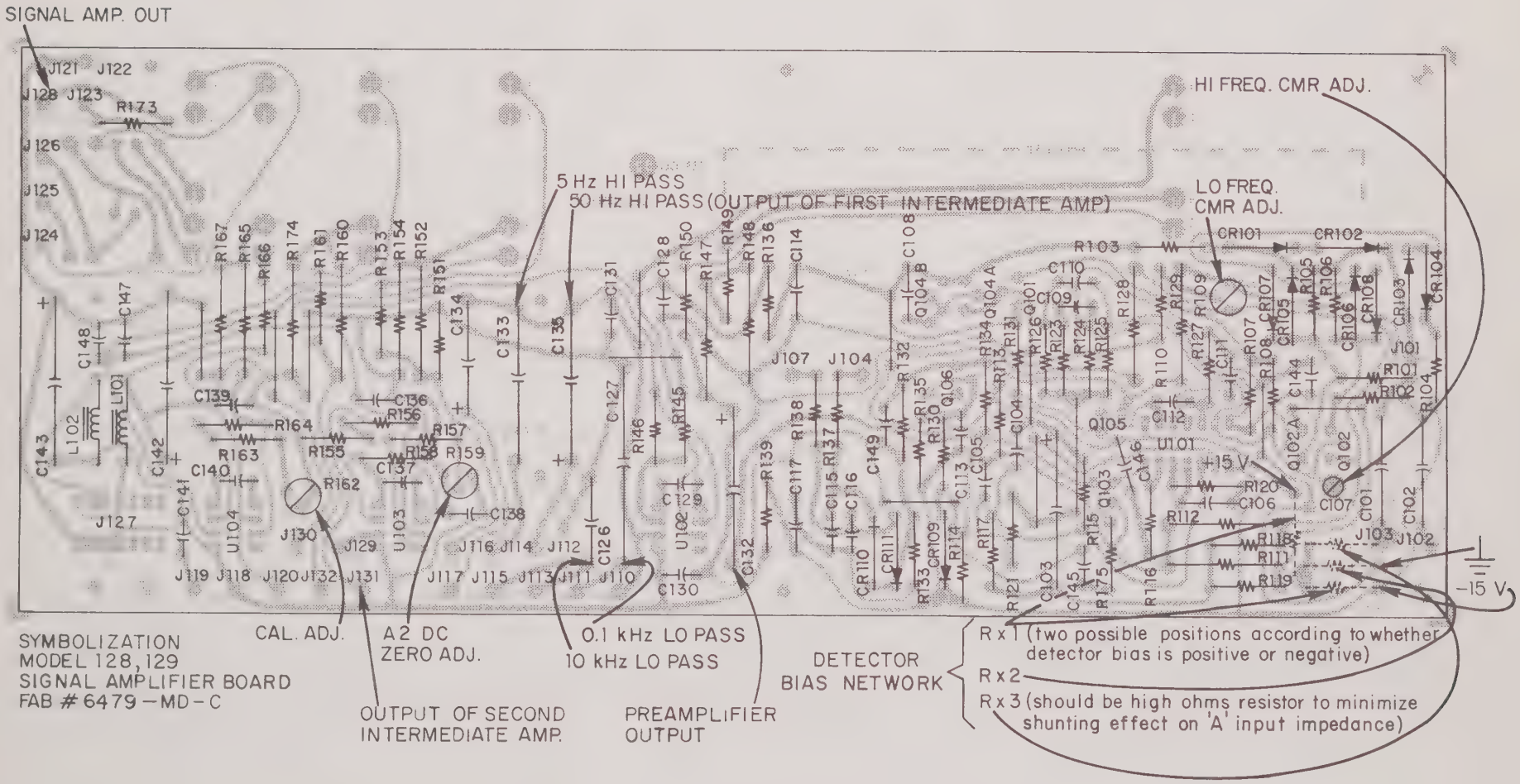
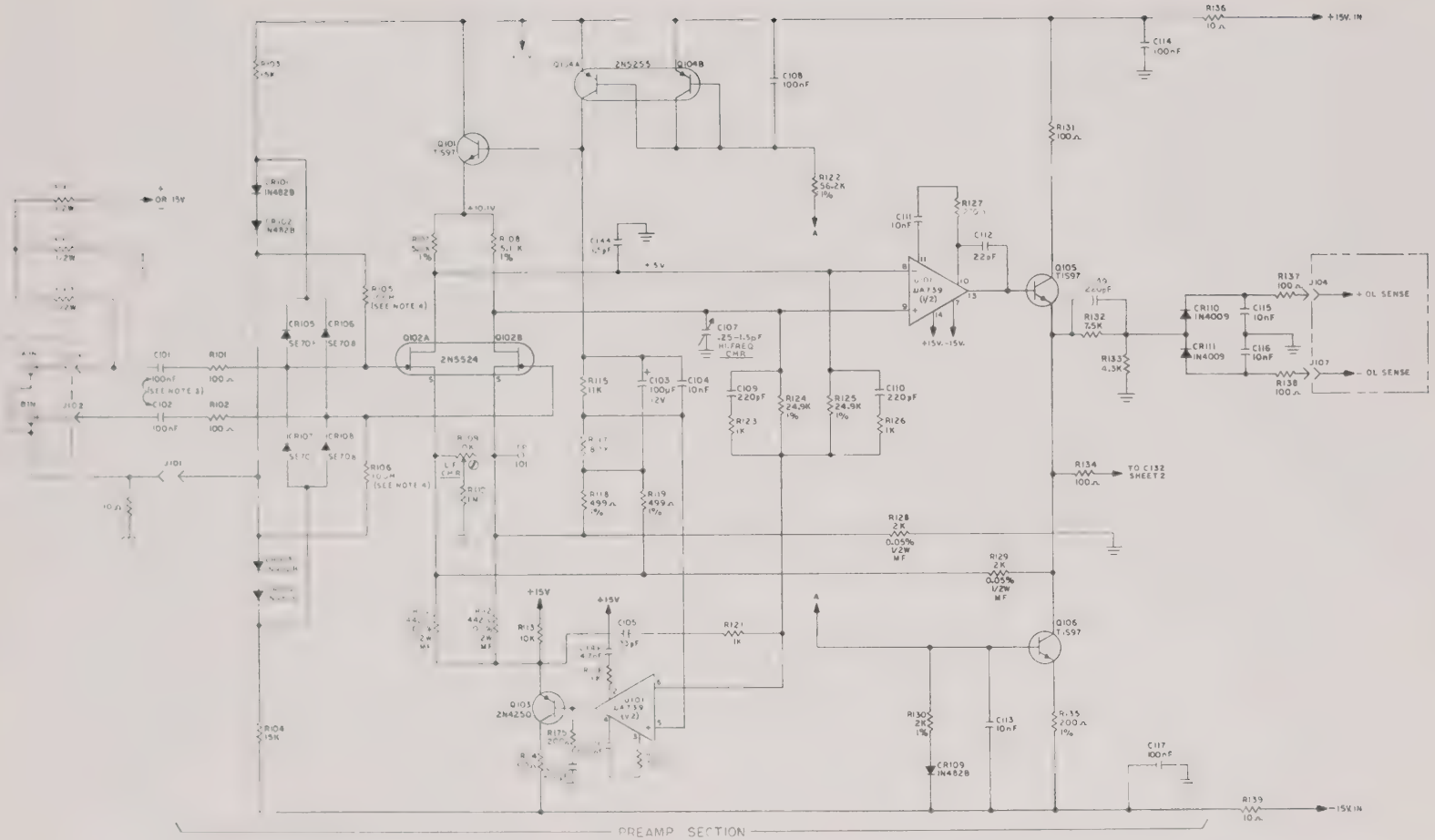

SIGNAL AMP. OUT
HI FREQ. CMR ADJ.
5 Hz HI PASS
50 Hz HI PASS (OUTPUT OF FIRST INTERMEDIATE AMP)
LO FREQ. CMR ADJ.
+15 V
-15 V
CAL. ADJ.
A2 DC ZERO ADJ.
0.1 kHz LO PASS
10 kHz LO PASS
OUTPUT OF SECOND INTERMEDIATE AMP.
PREAMPLIFIER OUTPUT
DETECTOR BIAS NETWORK
Rx1 (two possible positions according to whether detector bias is positive or negative)
Rx2
Rx3 (should be high ohms resistor to minimize shunting effect on 'A' input impedance)
SYMBOLIZATION
MODEL 128, 129
SIGNAL AMPLIFIER BOARD
FAB # 6479 — MD — C



NOTES

1. ALL RESISTORS 1/4W 5%, COMPOSITION UNLESS OTHERWISE NOTED.
2. ALL 1% RESISTORS 1/8W METAL FILM.
3. MATCHED PER PAR SPEC #700528
4. MATCHED PER PAR SPEC #700529.

SIGNAL AMPL BOARD MODEL 12-

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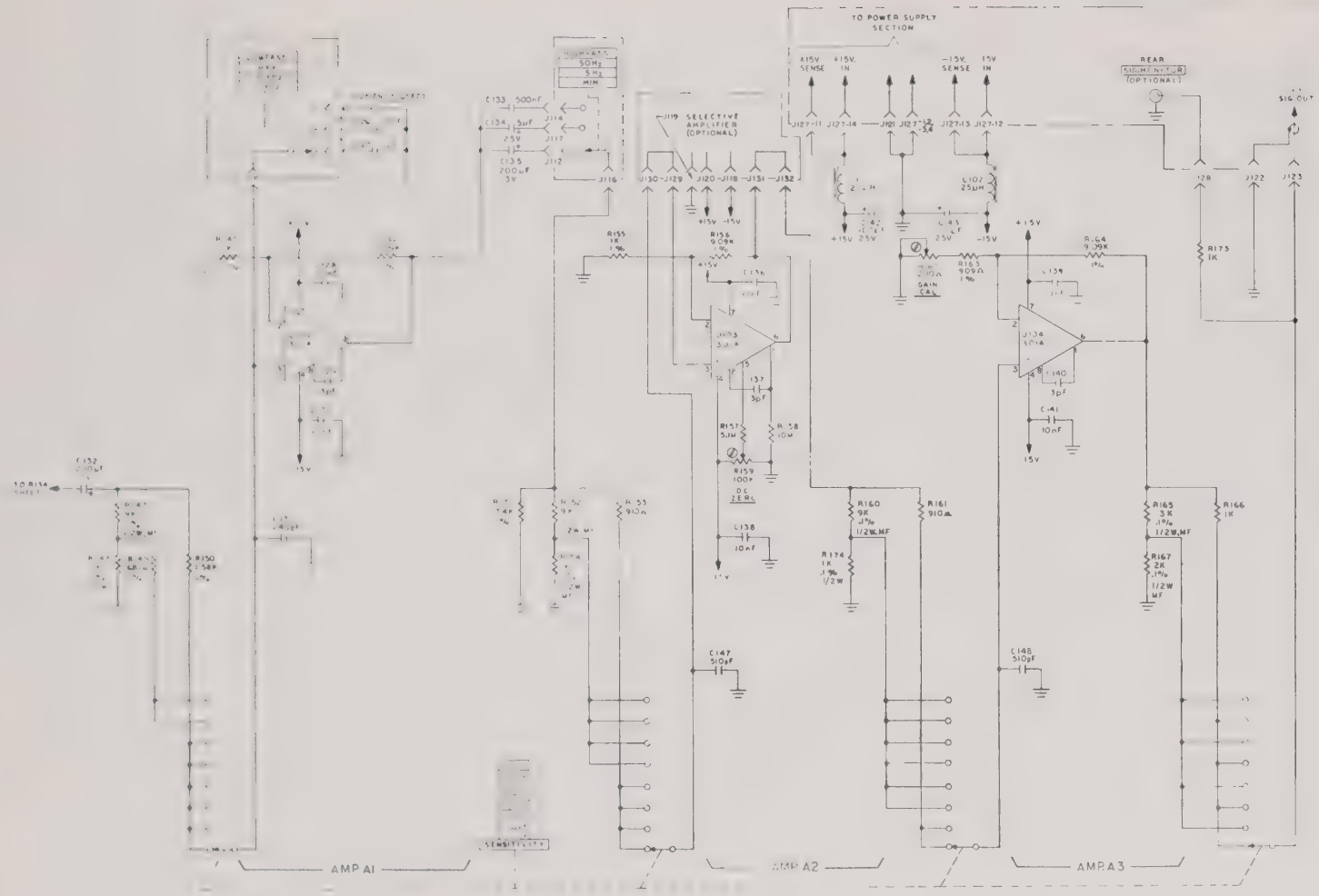

SIGNAL AMPLIFIER BOARD

MODEL 129

NOTES

SEE SH 1

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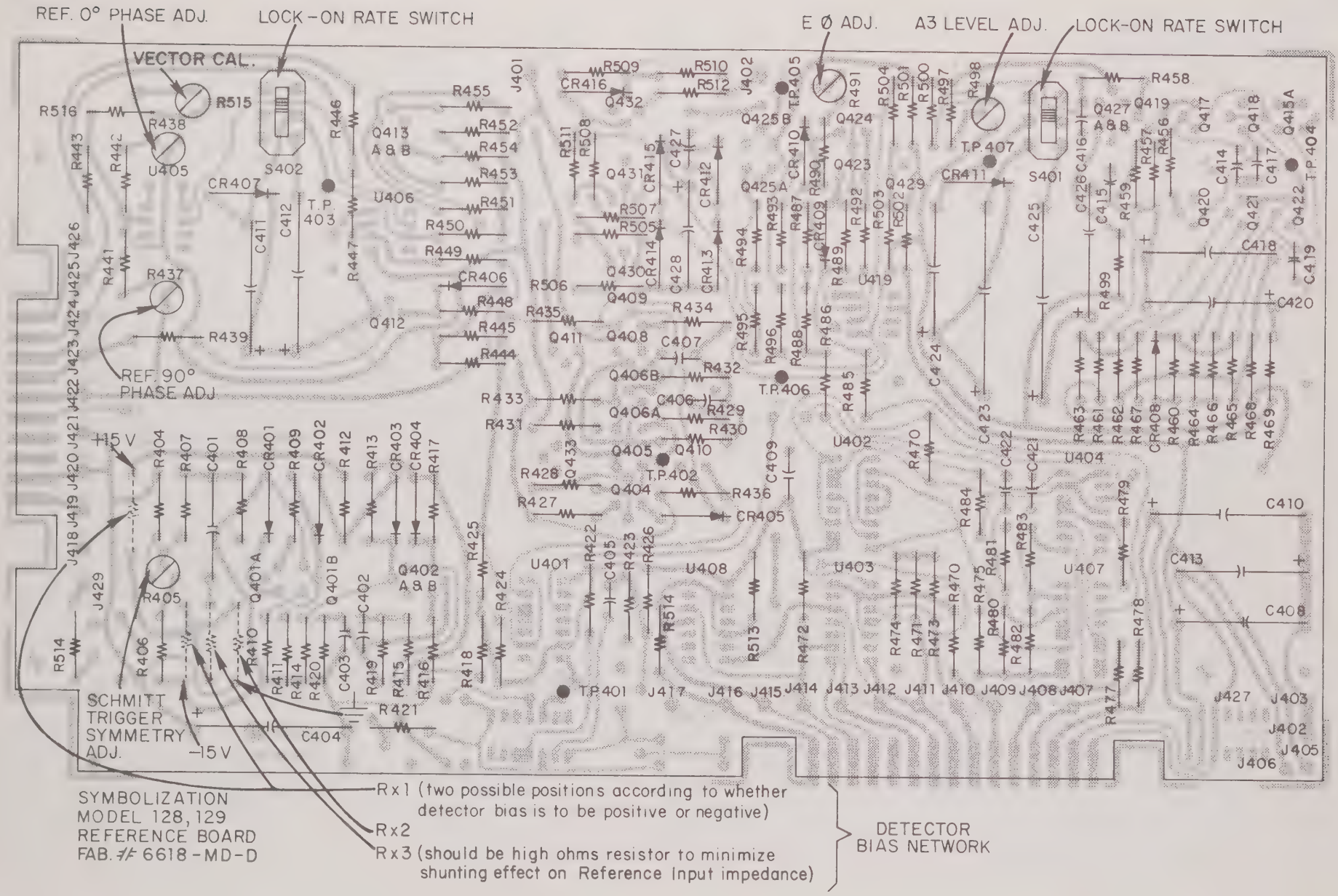
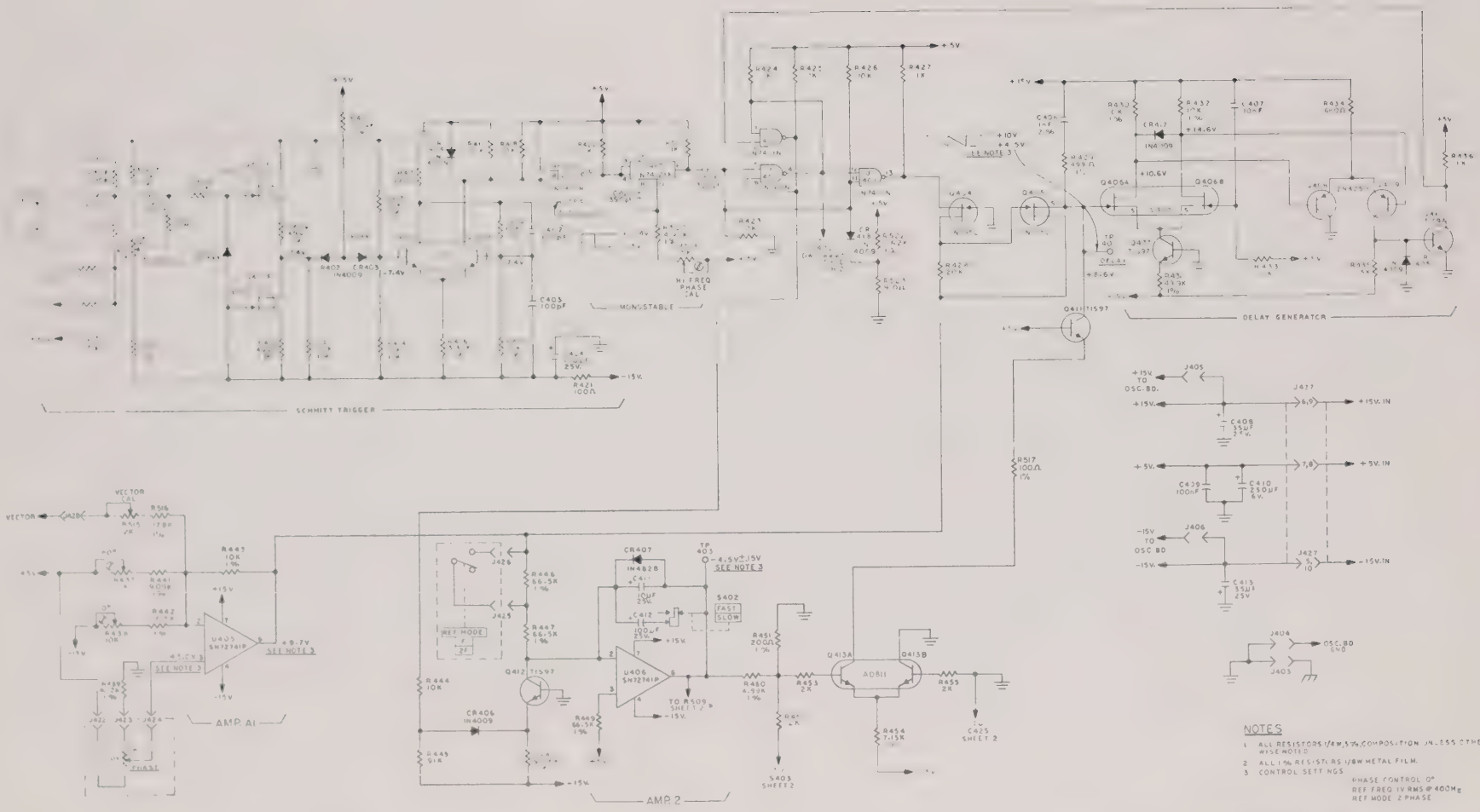

REF. 0° PHASE ADJ.
LOCK-ON RATE SWITCH
VECTOR CAL.
E Ø ADJ.
A3 LEVEL ADJ.
LOCK-ON RATE SWITCH
REF. 90° PHASE ADJ.
+15 V
−15 V
SCHMITT TRIGGER SYMMETRY ADJ.
SYMBOLIZATION
MODEL 128, 129
REFERENCE BOARD
FAB. # 6618-MD-D
Rx1 (two possible positions according to whether detector bias is to be positive or negative)
Rx2
Rx3 (should be high ohms resistor to minimize shunting effect on Reference Input impedance)
DETECTOR BIAS NETWORK



MODEL 129

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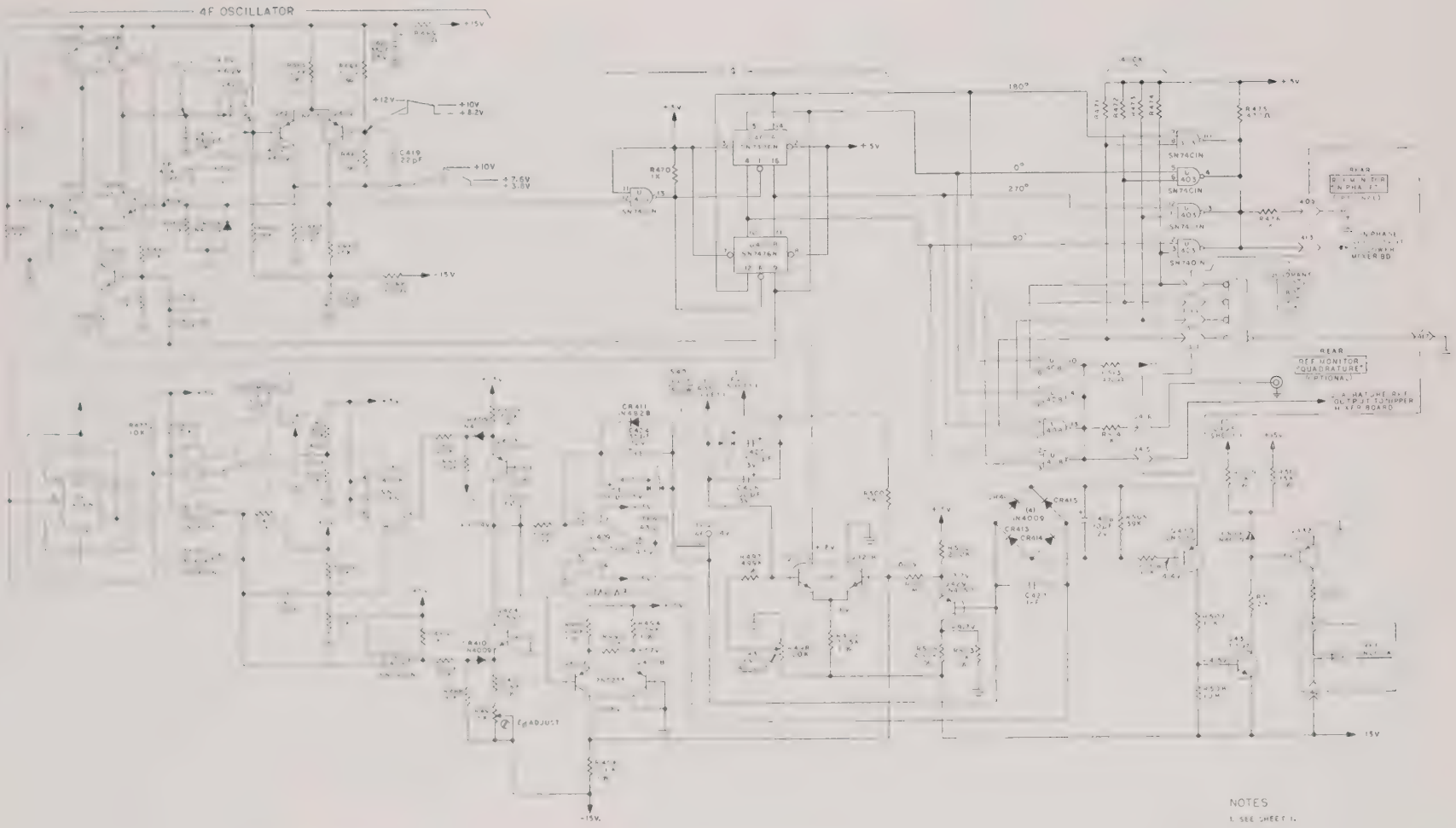

NOTES

1. SEE SHEET 1.

REFERENCE BOARD

MODEL 129

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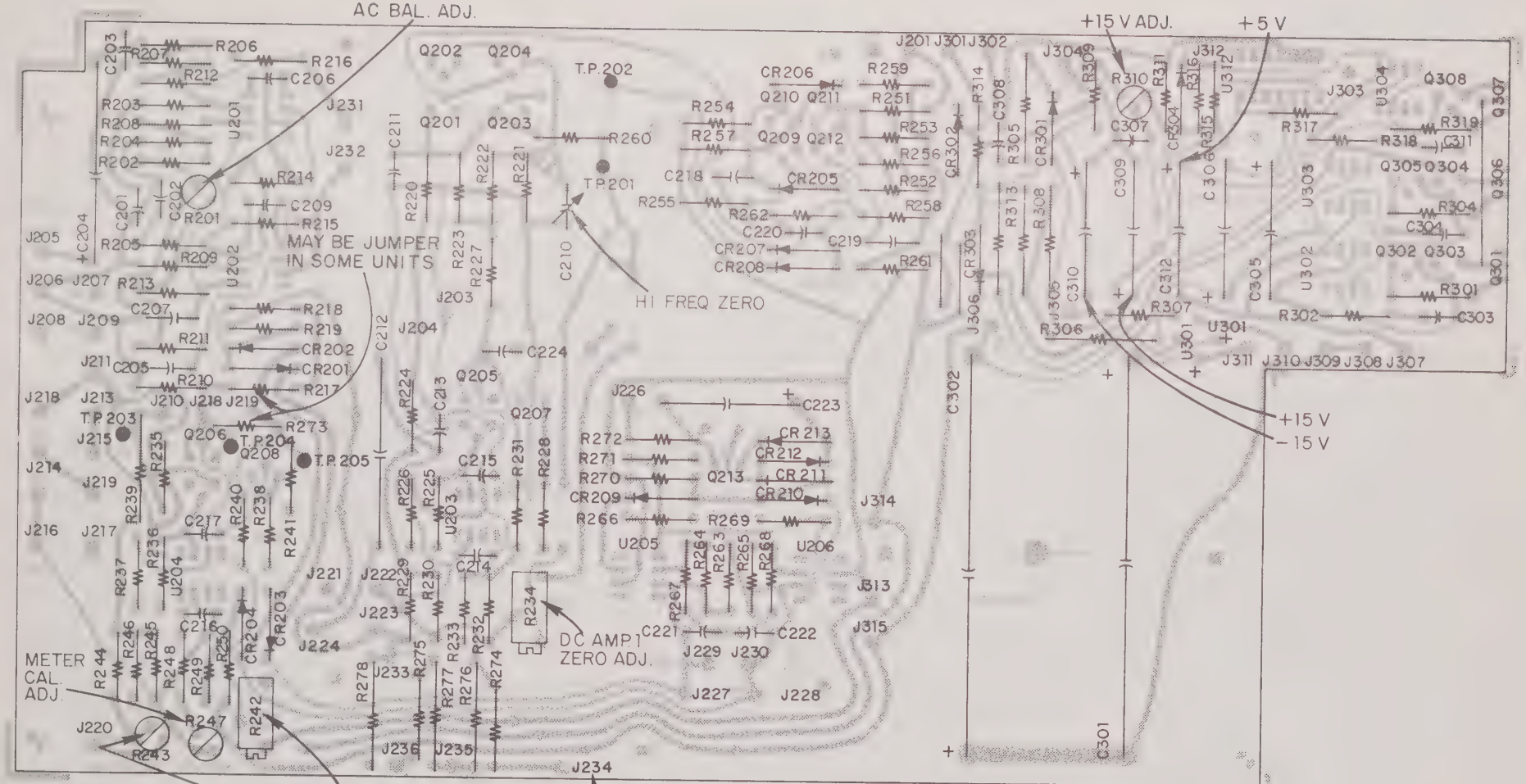
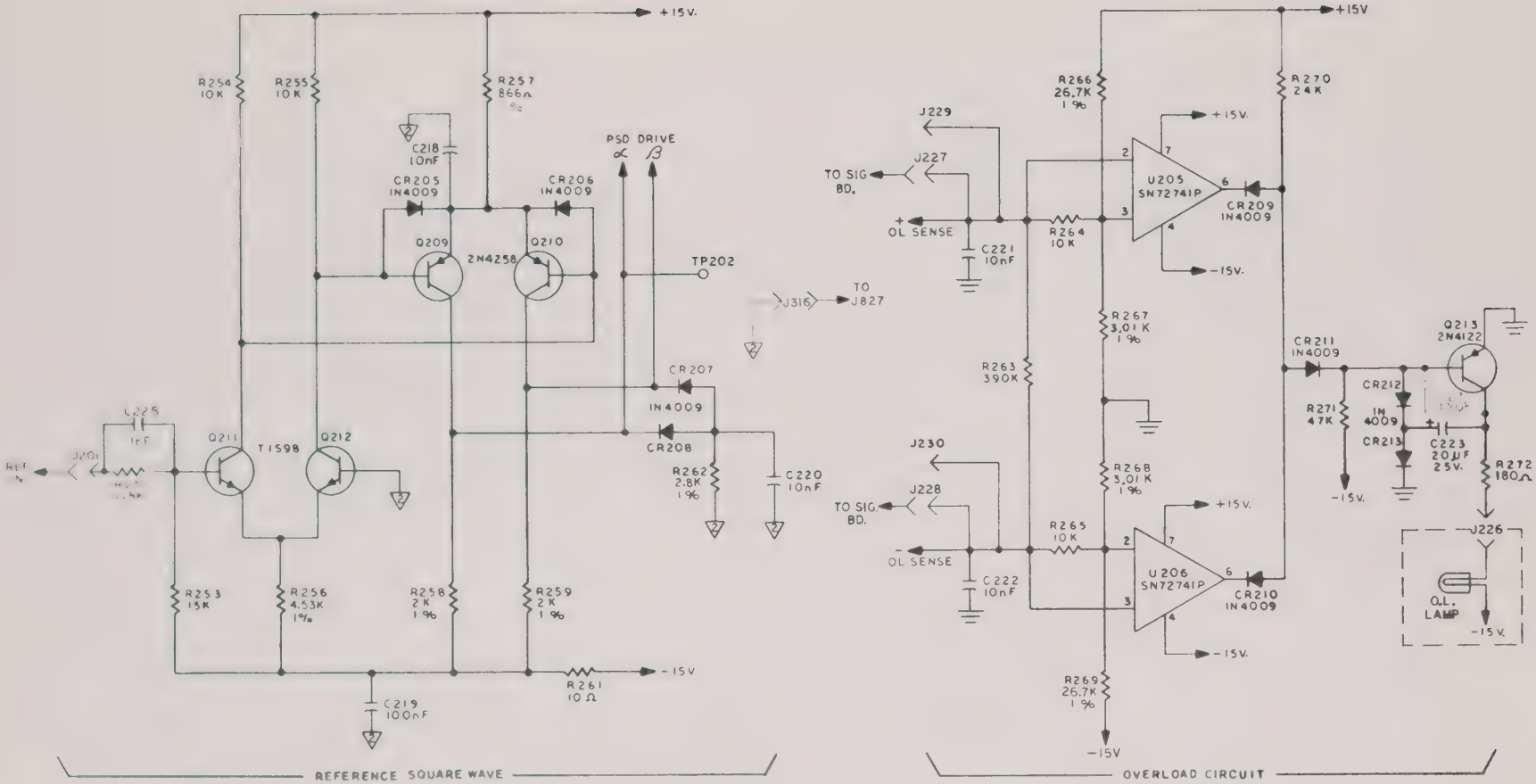
SHT 2 OF 2



SYMBOLIZATION
MODEL 128, 129
MIXER POWER SUPPLY BOARD
FAB #= 6583-MD-C



NOTES:

1. SEE SHEET 2/3

MIXER-POWER SUPPLY BD. MODEL 129

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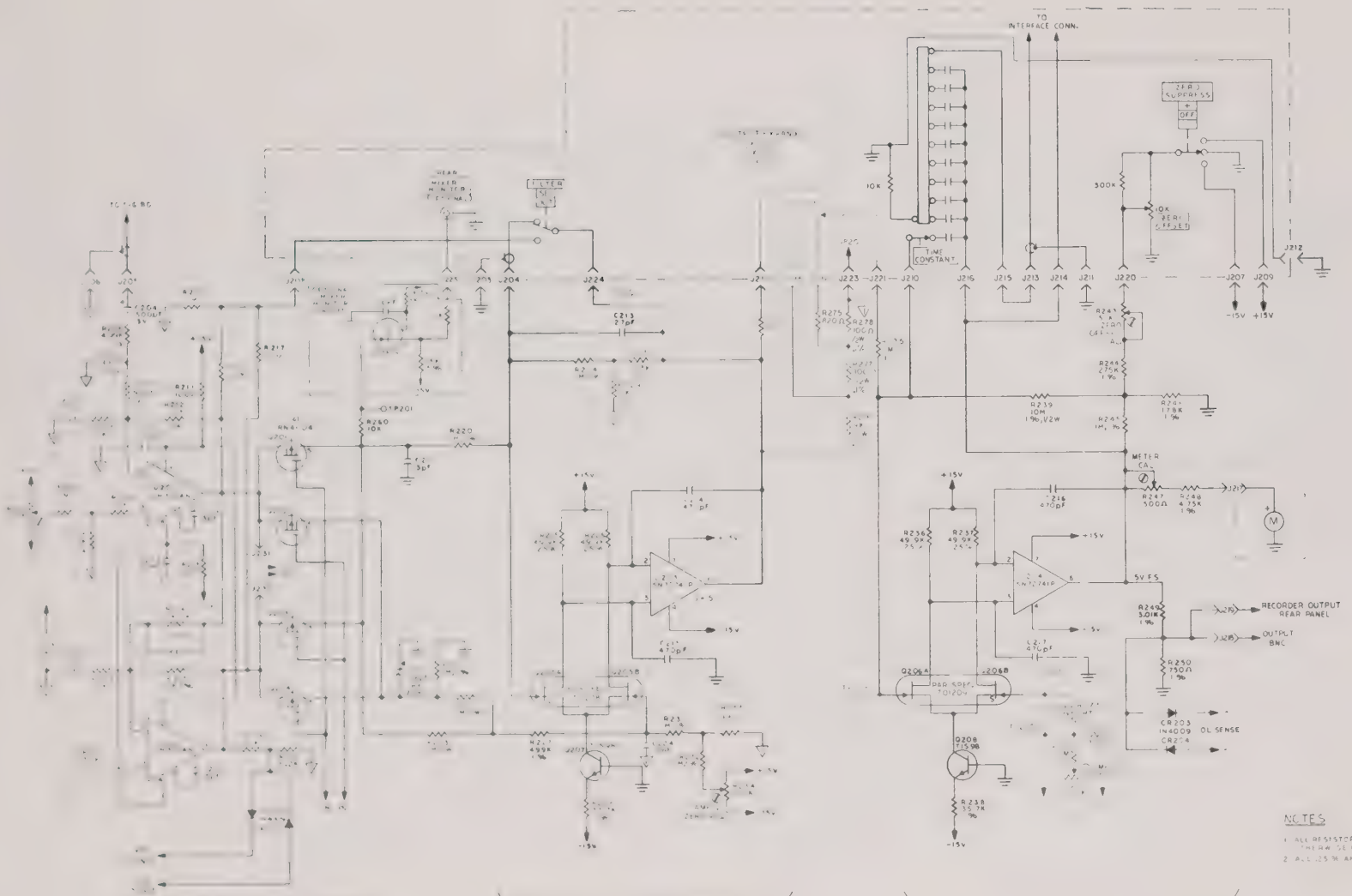

NOTES

1. ALL RESISTORS 1/4W, 5%, COMPOSITION UNLESS OTHERWISE NOTED
2. ALL .05% AND 1% RESISTORS 1/8W, METAL FILM

MODEL 129

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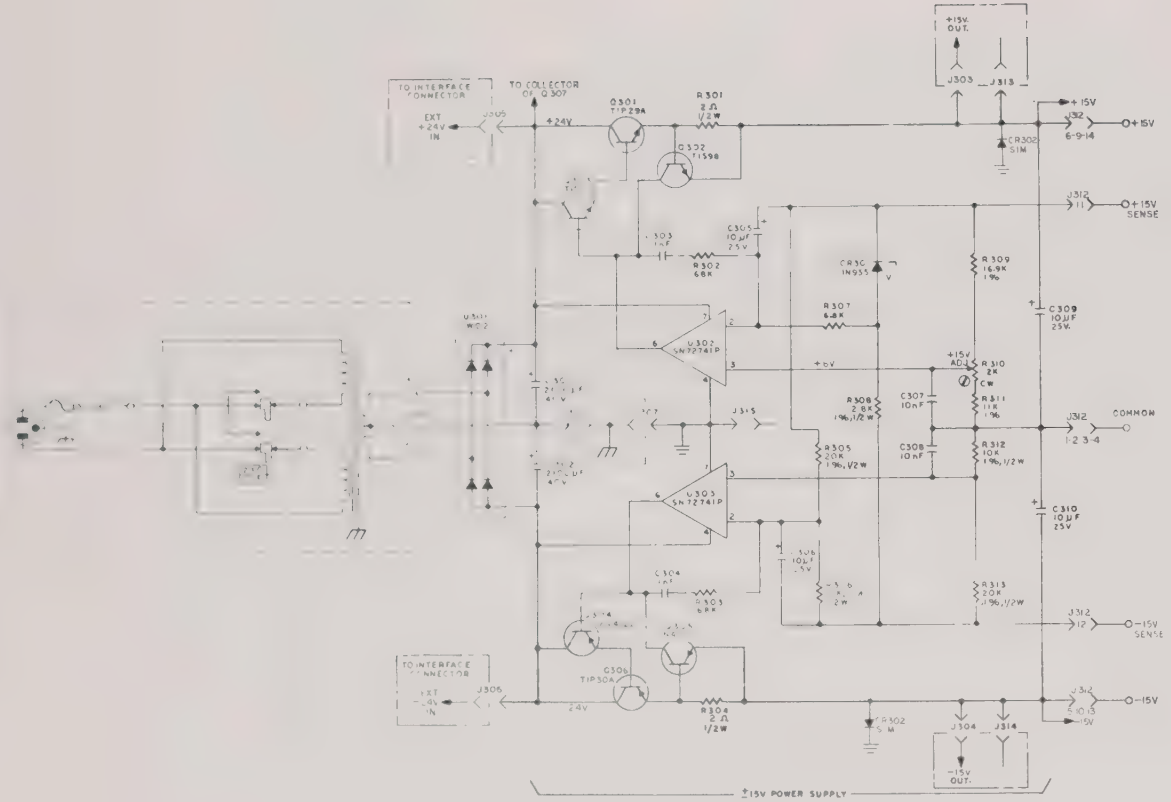
SHEET 2 OF 3



MIXER-POWER SUPPLY BD.

MODEL 129

NOTES

1. ALL RESISTORS 1/4W, 5% COMPOSITION UNLESS OTHERWISE NOTED.
2. ALL 1% RESISTORS 1/2 W METAL FILM
3. ALL 1% RESISTORS 1/8 W METAL FILM.

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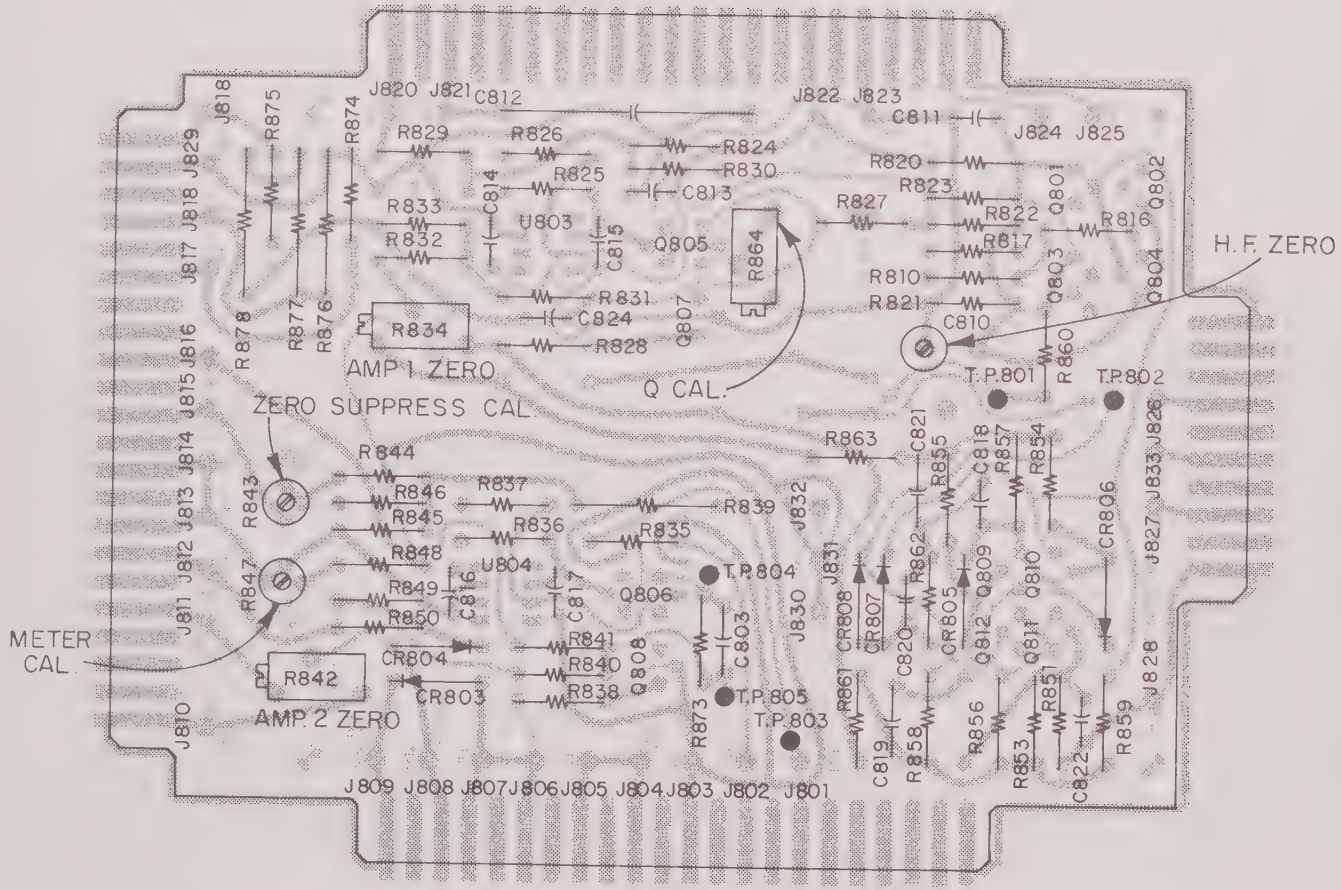
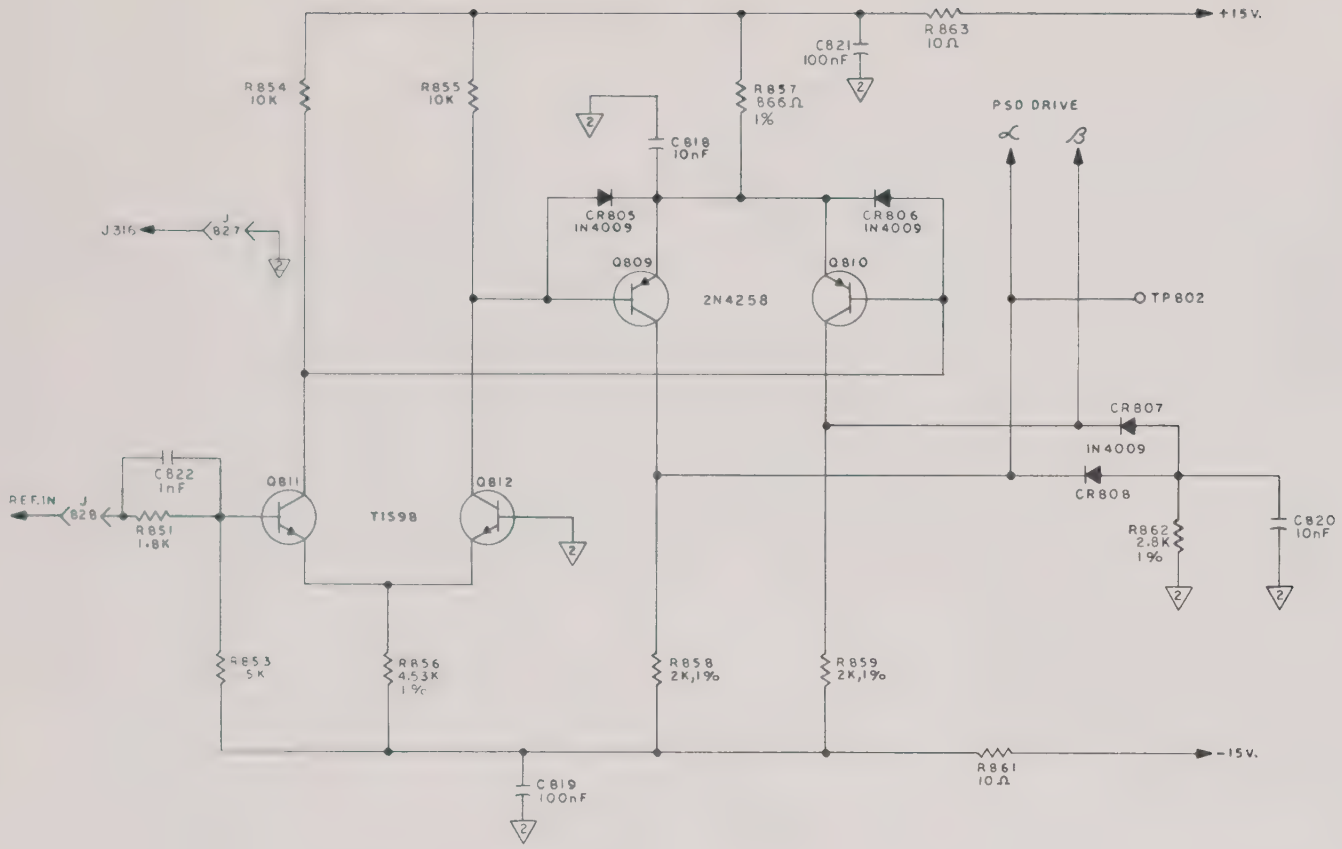
SHT 3 OF 3



SYMBOLIZATION
MODEL 129
Q MIXER BOARD
FAB. # 6731-MD-A



NOTES:

1. ALL RESISTORS 1/4W, 5%, COMPOSITION UNLESS OTHERWISE NOTED.
2. ALL 1% RESISTORS 1/8W, METAL FILM.

Q MIXER

MODEL 129

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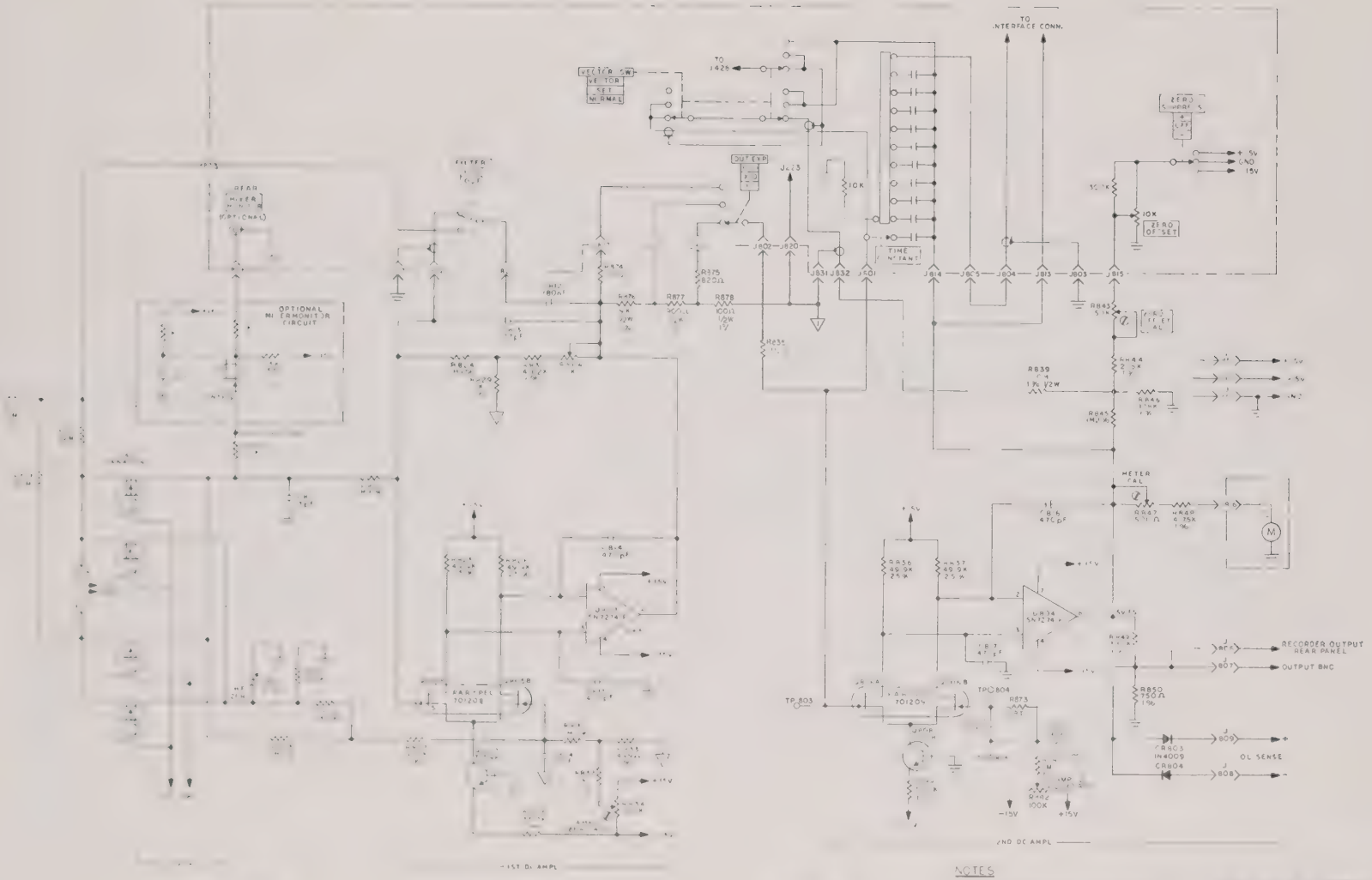

NOTES

1. ALL RESISTORS 1/4W, 5%, COMPOSITION UNLESS OTHERWISE NOTED
2. ALL 25% AND 1% RESISTORS 1/8W METAL FILM

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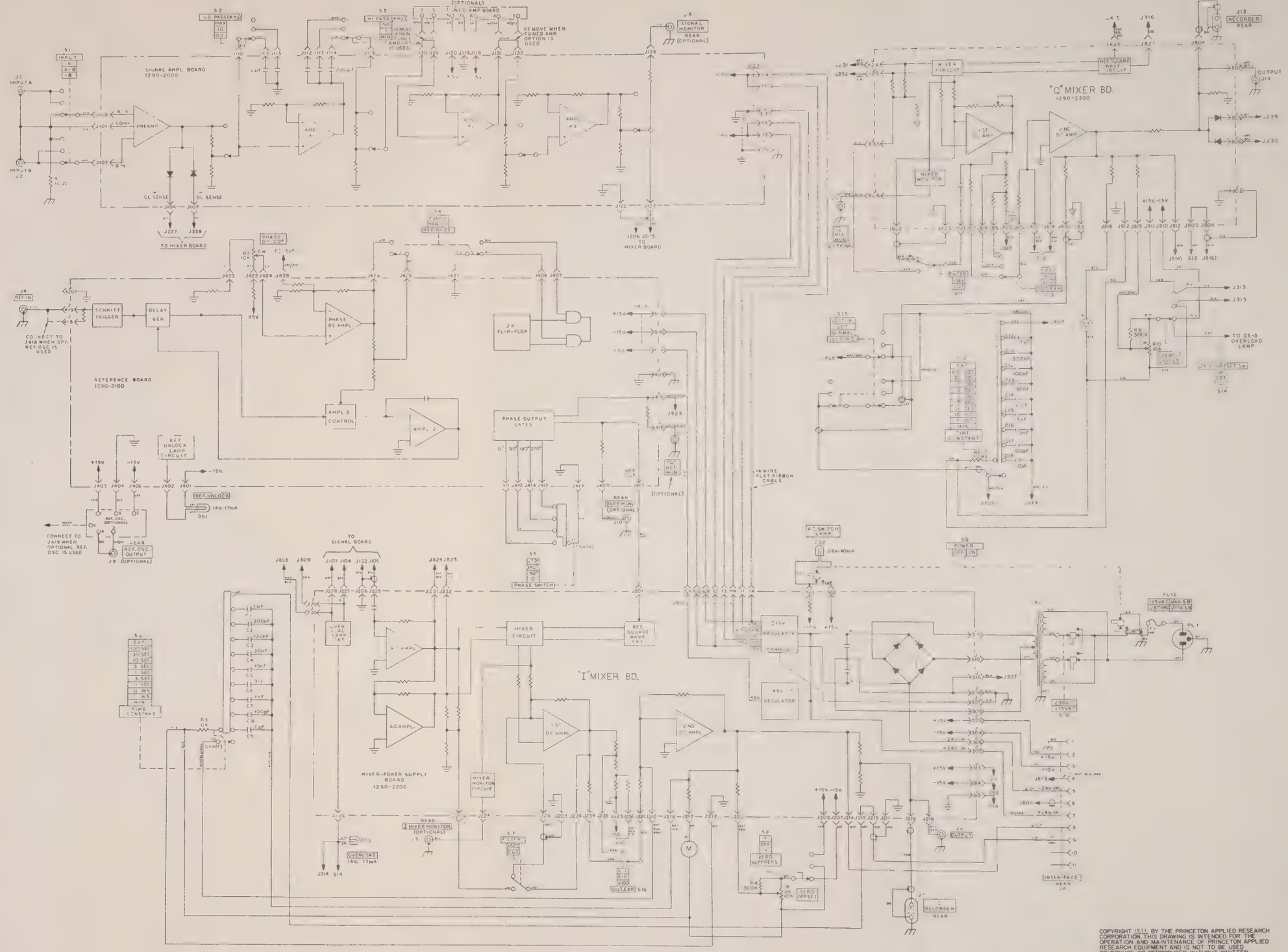
SHEET 2 OF 2 | 6735 | D | SY |



CHASSIS WIRING DIAGRAM

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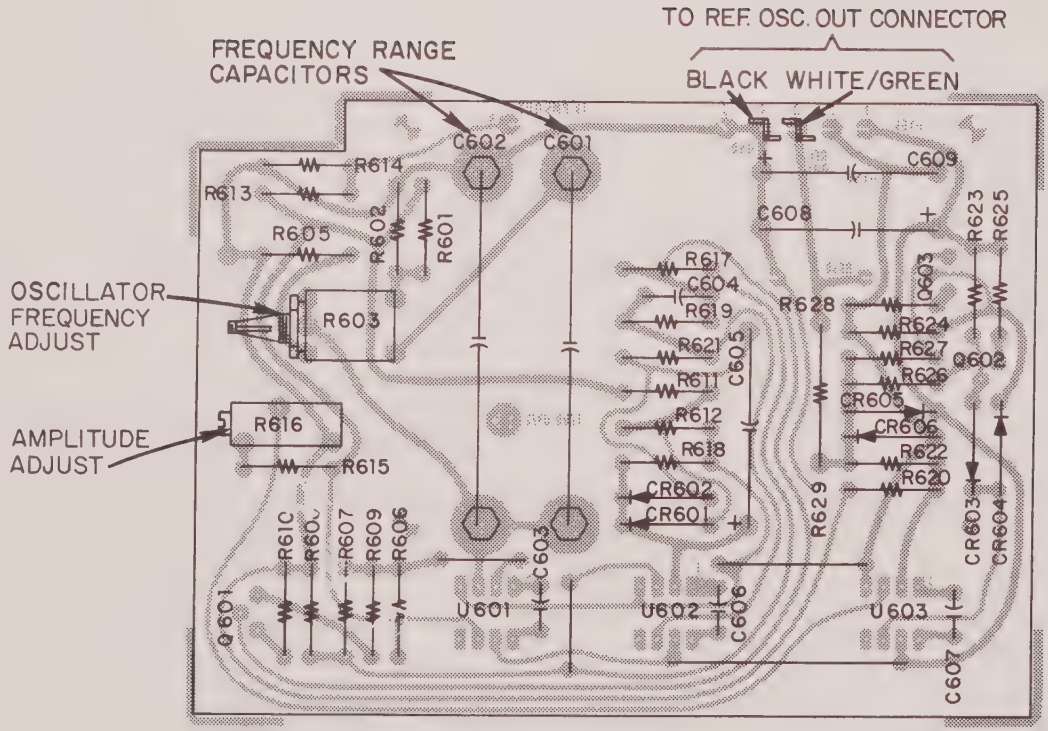
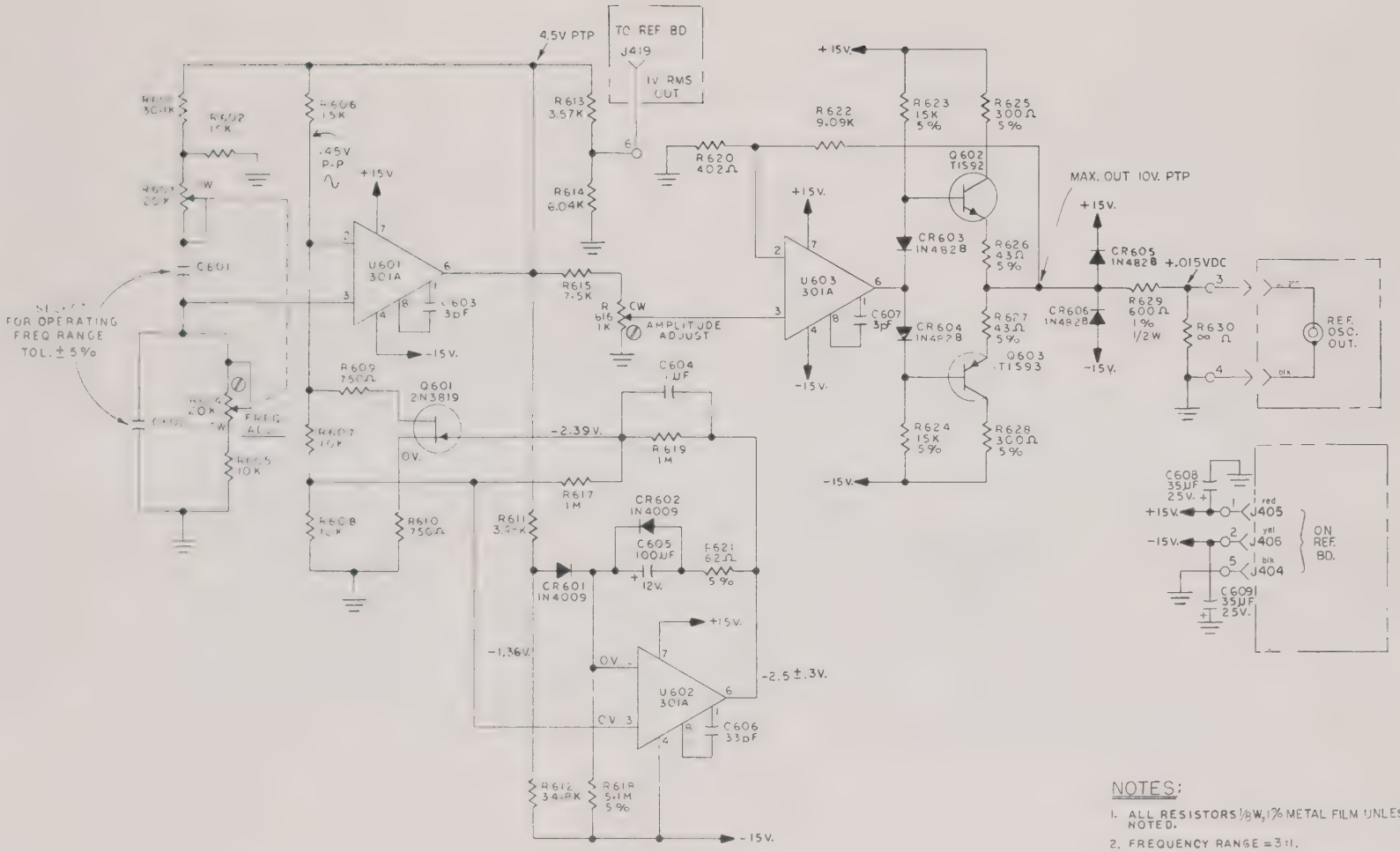
6852 | E | SD | A

MODEL 129



SYMBOLIZATION
MODEL 129/95 MODIFICATION
INTERNAL OSCILLATOR BOARD
FAB. 6662 —MD—



NOTES:

1. ALL RESISTORS 1/8W, 1% METAL FILM UNLESS OTHERWISE NOTED.
2. FREQUENCY RANGE = 3:1.
3. C ≅ 10/f μF.
4. ALL 5% RESISTORS 1/4 W CARBON COMPOSITION

INTERNAL OSCILLATOR MODIFICATION

MODEL 128

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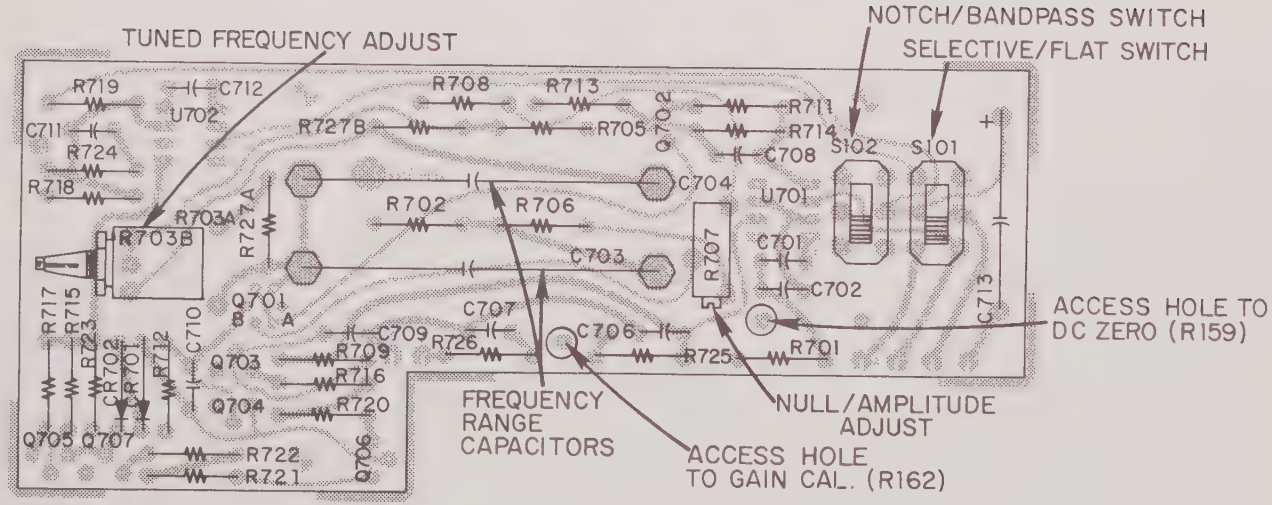
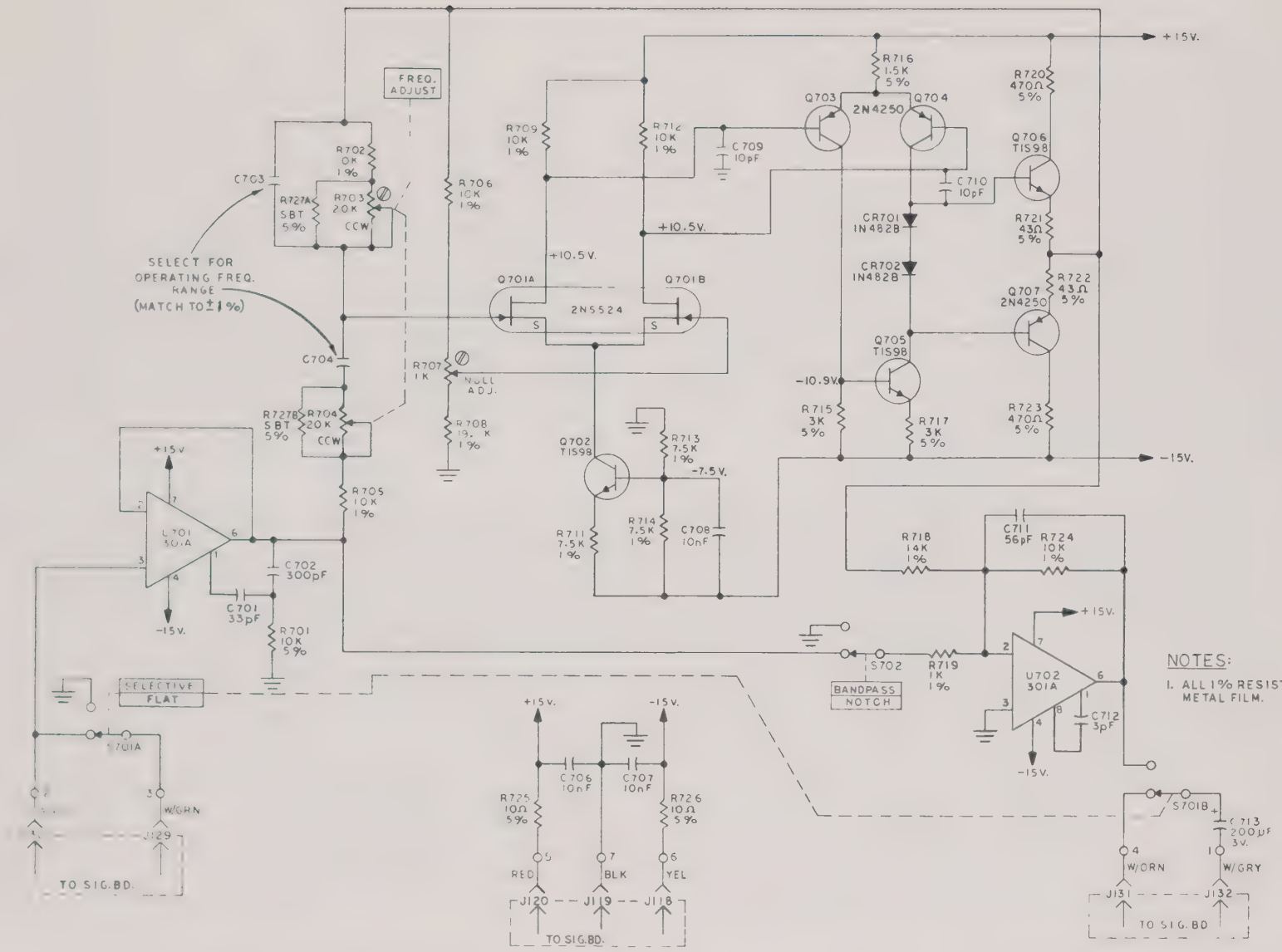
6645 C SD



SYMBOLIZATION
MODEL 129/84
TUNED AMPLIFIER MODIFICATION BOARD
FAB. #6973-MD-A



NOTES:

1. ALL 1% RESISTORS 1/8W METAL FILM.

TUNED AMPLIFIER MODIFICATION
128/98

MODEL 128

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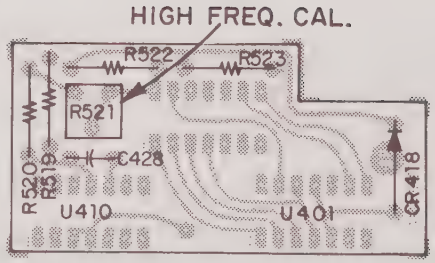
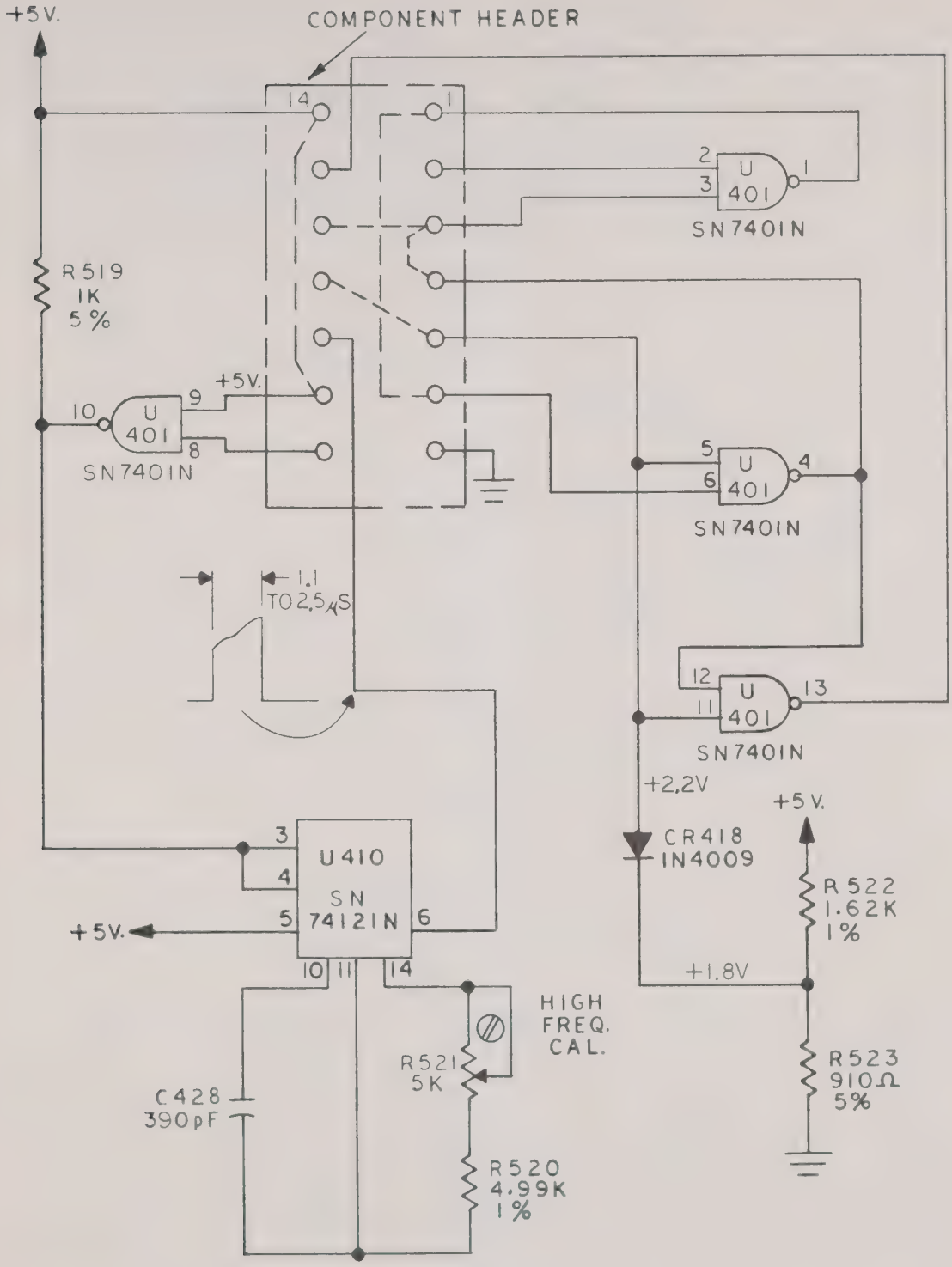
Although not shown in Figure V-1 (photograph of a prototype instrument), the Model 129 is equipped with a Phase Delay Module which introduces a delay in the Reference Channel of about half a microsecond to compensate high frequency phase shifts. The alignment procedure for this module is covered in the manual commencing with step 10 on page V-10.



SYMBOLIZATION
MODEL 129
PHASE DELAY MODULE BOARD
FAB. #7220-MD-



LINEAR REF. PHASE DELAY MODULE

MODEL 129

7228 | A | SD

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